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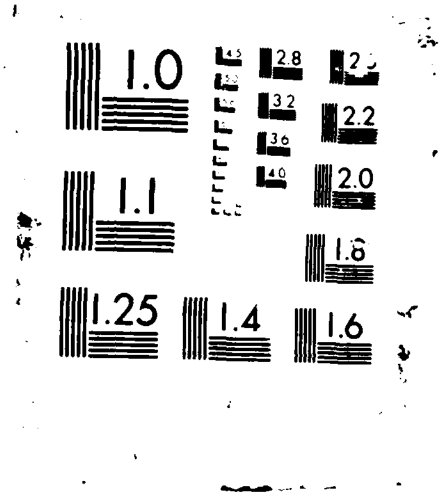
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AD-A176 506

A DENDROCLIMATIC ANALYSIS OF FLUCTUATIONS

IN THE GREAT SALT LAKE

by

William J. Delehunt

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Soil Science and Biometeorology

Approved:

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Committee Member

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Bill Delehunt

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ABSTRACT

A Dendroclimatic Analysis of Fluctuations
in the Great Salt Lake

by

William J. Delehunt, Master of Science
Utah State University, 1986

Major Professor: Dr. Gail E. Bingham
Department: Soil Science and Biometeorology

The purpose of this study was to examine tree ring data so as to reconstruct past levels of the Great Salt Lake. Precipitation data was regressed on the tree data and on lake levels to determine which precipitation measuring stations show the highest correlation with increases in the growth patterns of the trees and the fluctuations in the Great Salt Lake. A predictive equation was developed by regressing tree ring indices on lake levels.

Tree ring indices were correlated with each other. No definitive relationship was found between distance and correlation value. Most likely, microsite climatic features have at least as much influence or tree growth as does spatial separation.

Precipitation data from stations around Utah were regressed on the lake level. Correlation is relatively poor, with an R squared value of 47% between stations and yearly Great Salt Lake levels, and 49% between stations and a ten year running mean of lake levels.

Regression of tree ring indices on measured, pristine and modified lake levels gave R squared values of 49.5%, 38.8% and 53.0%, respectively. Regression between trees and lake area gave an R squared value of 49.5%.

The maximum recorded level for the lake, measured in 1986, is 4211.8 feet (MSL). Results indicate the lake has been at least this high previously, and may have hit a maximum four to fourteen feet higher after 1610 AD.

The major limitations of this study were:

Tree ring sites are not in the Great Salt Lake drainage basin, and are therefore only an estimate of the amount of precipitation falling there;

Tree ring indices end, for the most part, before the most recent lake rise, and this information, which would be very important in the regression equation, is unavailable.

(67 pages)

INTRODUCTION

In the past several years, the Great Salt Lake has risen dramatically. In 1983 alone, floods caused by rising lake levels caused 40 million dollars worth of damage in Salt Lake City. Loss of marsh land at Farmington Bay, Bear River Refuge, Ogden Bay and other federal, state and local wildlife areas is incalculable, but an estimated 35 million dollars in damage was done just to permanent buildings at these sites (Ware, 1984).

Since 1851, when settlers in the Great Salt Lake Valley first started measuring water levels, the lake has fluctuated only 20 feet, from a low of 4191.35 feet above mean sea level (MSL) in 1963 to a record high in 1986 of 4211.8 feet MSL. The mean level is 4201.77, with a standard deviation of 4.44 (Kay and Diaz, 1985). When the lake hit a high of 4211.6 feet MSL in 1873, the Mormon settlers proposed pumping water out of the lake and into the desert to the west. This plan was abandoned a few years later as the lake receded. Present day problems began after the lake level reached a minimum in the early 1960s. Residents began building on the newly exposed beach front property (Arnow, 1979). As the lake began to rise again in the mid 1970s, several plans to control the lake's growth were put forth. The Southern Pacific Railroad had a solid causeway which spanned the lake, effectively dividing it into two sections, north and south. This division caused the southern end of the lake, which is closest to the large population centers of Ogden and Salt Lake City, to be higher by

as much as 3.25 feet (Simon, 1984). A breached bridge was made in the causeway in 1985, easing the situation somewhat by allowing the lake to come close to equilibrium. In 1976, as the lake rose to 4202 MSL, the pumping plan was again considered. In 1979, the Utah State Legislature defined the Great Salt Lake as waters within a perimeter established by the 4212 meander line, and passed a bill limiting the lake level to 4202 MSL (House Bill 120). Between 1982 and 1983, the lake rose four feet, to 4204.7 MSL, surpassing the mandated maximum level. Since the lake is only 34 feet deep at most, this one year rise covered an additional 267 square miles of water front property (Ware, 1984). In 1986, as the Great Salt Lake reached its recorded maximum level, the Legislature approved the pumping plan.

The question asked most often of meteorologists and climatologists is, "*Has the lake reached its peak, or will it continue to rise?*" With the limited scope of present day weather forecasting, this question is nearly impossible to answer, but a thorough analysis of available climatic data may reveal some clues. Great Salt Lake water levels have been measured for 130 years. Synoptic weather observations, specifically temperature and precipitation data, have been collected in the intermountain west since the late 19th century. While at first these may seem to be long data bases, they are in fact very short on a climatic scale. Since the periodicity of the Great Salt Lake may be on the order of decades or longer, these records are much too short to be used to analyze fluctuations in the Great Salt Lake.

Another source of climatic data is locked away within the growth records of trees. In the early 20th century, astronomer A. E. Douglas,

working in Arizona, discovered the annual growth rings of trees were similar for trees growing in the same area at the same time. By comparing the ring widths of living trees with tree stumps, he could accurately discern the year in which the trees had been cut down. As Douglas collected more and more samples from both living trees and stumps, he was able to recreate the chronology of tree growth in Arizona. In the mid 1920s, while working with wooden beams found in the ruins of Mesa Verde, Douglas was able to match the tree rings in the beams to his fixed chronology, and accurately date the age of the settlement. The science of dendrochronology was born, and Douglas was eventually able to stretch his chronology back to 11 A.D. (Webb, 1983).

LITERATURE REVIEW

The Laboratory of Tree-Ring Studies was founded at the University of Arizona to continue Douglas' dendrochronologic work. Plant physiologists know a biological process such as growth cannot proceed faster than is allowed by its most limiting factor, which may be either internal or external to the plant. If the factor changes in some way so as to no longer be limiting, the rate of growth will increase until some other factor becomes limiting.

The two most limiting factors in plant growth in environments such as the western United States are available water and temperature. Except for high latitude, high altitude situations, moisture is generally considered to be the more limiting of the two (Kleine, et. al., 1936; Fritts, 1965; Fritts, et. al., 1965; Stockton and Fritts, 1973; LaMarche, 1974). Additionally, tree growth is at least as dependent on the previous year's precipitation as on the current growing season's (Fritts, et. al., 1965; Fritts, 1971; Meko and Stockton, 1983), because late season conditions influence food accumulation and reserves, and replenish soil moisture, preconditioning the tree and setting conditions for the next year's bud initiation. With trees as old as the ones used in this study, the root systems reach great depths. This late season precipitation can fill the soil buffer, allowing the trees to survive and flourish even during a drought-plagued growing season by transporting water from well below the soil surface. This is especially true in the southwestern United States; in the northeast, and in Europe,

where conditions are not as arid, the correlation between current growing season precipitation and tree ring width is higher than that of the previous year's precipitation and tree growth.

The Utah State Office of Climatology has received tree ring records from sites in northeast Utah, southern Idaho and eastern Nevado. These data sets were collected by the Tree Ring Laboratory of the University of Arizona, and have been standardized so as to allow a comparison between them. Standardization involves converting actual tree ring widths to tree ring indices, and removes the variability of rings due to the age of the tree (all things being equal, younger trees will produce larger rings than older trees, due to a difference in overall volume of the tree). A tree ring index is a percentage of expected growth and is formed in two steps. First a quadratic polynomial is fit or cubic spline smoothing techniques are applied to the actual tree ring widths. This yields an expression which gives an estimate of tree growth for each year. By then dividing this estimate into the actual ring width for each year, the tree ring index is obtained.

Dendroclimatology is a relatively new science, in which ring indices are compared and evaluated so as to reconstruct past climatic conditions and changes. Analysis of tree rings in the Midwest (Lansford, 1979; Blasing and Duvick, 1984; Meko, et. al., 1985) have led researchers to predict a drought for the mid 1990s, based solely on tree growth cycles. Another study in northern Canada explained 57-80% of the variability in water levels at Lake Athabasca (Stockton and Fritts, 1973).

Previous studies have shown a good correlation between tree sites separated by less than 100 miles (161 km). The most recent work done in this area (Cropper and Fritts, 1982), performed extensively in the Four Corners area of the American southwest, showed 50% of the climatic signal is common to tree stands within 100 miles of each other. That is, correlations between stands showed half of the climatic signal was common, as evidenced through similar growth patterns. Additionally, there is a good correlation between tree growth and precipitation records from stations as far as 32 kilometers or more from the tree site (Fritts, 1965).

To summarize, tree ring studies in the past have shown good correlations between precipitation records and between tree sites. These methods will be applied to the data from the area around the Great Salt Lake to reconstruct lake levels. It is important to remember this dendroclimatic analysis is based on empirical relationships. In the words of Harold C. Fritts,

> The results of this study depend exclusively on statistical correlations between tree growth and climatic factors to sort out probable relationships from a great many possible ones. Such an approach cannot prove cause and effect. It is not offered as a substitute for experimental research into the environmental controls of growth, but rather as a means of establishing the information on past climate that a particular ring-width chronology may contain (Fritts, 1974, p. 412).

OBJECTIVES

The main objective of this study was to determine if statistical relationships exist between tree growth, precipitation amounts and lake water levels, to see if there is a recurring cyclic pattern of maxima and minima. Such a definable pattern would aid law makers and local residents in long range planning for management of the Great Salt Lake. Specific objectives are as follows:

1. A correlation between tree ring sites will be performed to ascertain a relationship between separation distance and percent of climatic signal shared by the sites.

2. Regression analysis will be used to match each tree site in this study with the most appropriate meteorological data gathering location.

3. Multiple regression techniques will be used to compare Great Salt Lake water levels with the tree ring sites, to determine which of the sites best correlate.

METHODS

Tree ring data from sixteen sites in Nevada, Idaho and Utah were used in this study. Each site contains between one and 34 tree samples for each year, and this number varies for each site from year to year. While each site actually contains more than one tree, and the same tree is not necessarily alive throughout the time span covered by the site, it is convenient to think of each site as a single tree. This is a necessary simplifying assumption, and makes no difference in the analysis. Table one summarizes pertinent data associated with these sites. Figure one shows the locations of the sites.

Correlations were performed between all possible combinations of tree sites, to verify the 161 kilometer - 50% climatic signal relationship. Since the tree data sets are of different lengths and cover slightly different time frames, the period 1690-1976 was chosen for the correlations. This limited the amount of missing data to less than 5% for each data set.

Precipitation data from twelve sites in Utah were used. Reporting stations were chosen for their proximity to tree ring sites and for the length and completeness of the data set. Table 2 lists each precipitation reporting site, its location, length of data set and percentage of missing data. Locations of the sites are shown in Figure 2.

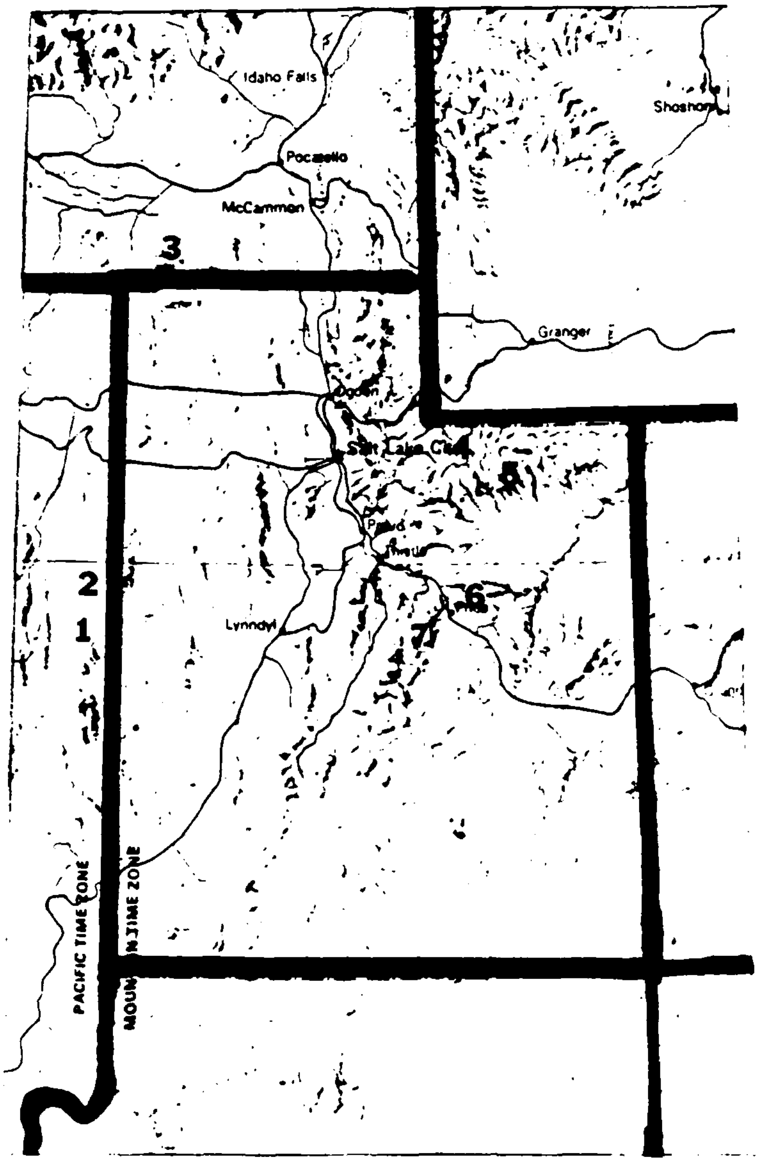
Precipitation values were regressed on tree ring indices. Table 3 lists each tree site and the precipitation station used in each regression. Since the Hiawatha data set was relatively short, Ft. Duchesne was also regressed on Nine Mile Canyon.

Table 1. Tree ring indices.

Station Name / Type of Tree	State / Maximum Number of Trees / Length of the Data Set	Abbreviation / Location
Upper Timber Creek Bristlecone	Nevada 15 800 - 1976	UPPER 39 25'N 114 39'W
City of Rocks, One Limber Pine	Idaho 12 1200 - 1980	CITY1 42 05'N 113 43'W
City of Rocks, Two Limber Pine	Idaho 45 1120 - 1980	CITY2 42 05'N 113 43'W
Nine Mile Canyon (High) Douglas Fir	Utah 14 1200 - 1964	NINE 39 47'N 110 18'W
Pony Express Pinyon Pine	Nevada 30 1400 - 1982	PONY 39 49'N 114 37'W
Uinta Mountains, Site D Pinyon Pine	Utah 8 1430 - 1971	UINTAD 40 37'N 109 57'W
Conners Pass Pinyon Species	Nevada 29 1480 - 1982	CONNER 39 02'N 114 37'W
Egan Range West Single-Needle Pinyon	Nevada 8 1500 - 1976	EGAN 39 23'N 114 55'W

Table 1. (Continued)

Emery, Link Canyon Road Ponderosa Pine	Utah 17 1540 - 1964	EMERY 38 59'N 111 19'W
Duck Creek Canyon, West Single-Needle Pinyon	Nevada 11 1570 - 1976	DUCK 39 20'N 114 45'W
Berry Creek Single-Needle Pinyon	Nevada 13 1610 - 1978	BERRY 39 22'N 114 43'W
Horse Canyon Ridge Single Leaf Pinyon	Nevada 14 1610 - 1978	HORSE 39 16'N 114 07'W
Uinta Mountains, North Englemann Spruce	Utah 18 1610 - 1971	UINTAN 40 57'N 110 26'W
Uinta Mountains, Site C Douglas Fir	Utah 18 1690 - 1978	UINTAC 40 34'N 109 57'W
Smith Creek Canyon Single-Needle Pinyon	Nevada 13 1690 - 1978	SCC 39 17'N 114 08'W
City of Rocks, Three Limber Pine	Idaho 35 1700 - 1978	CITY3 42 05'N 113 43'W

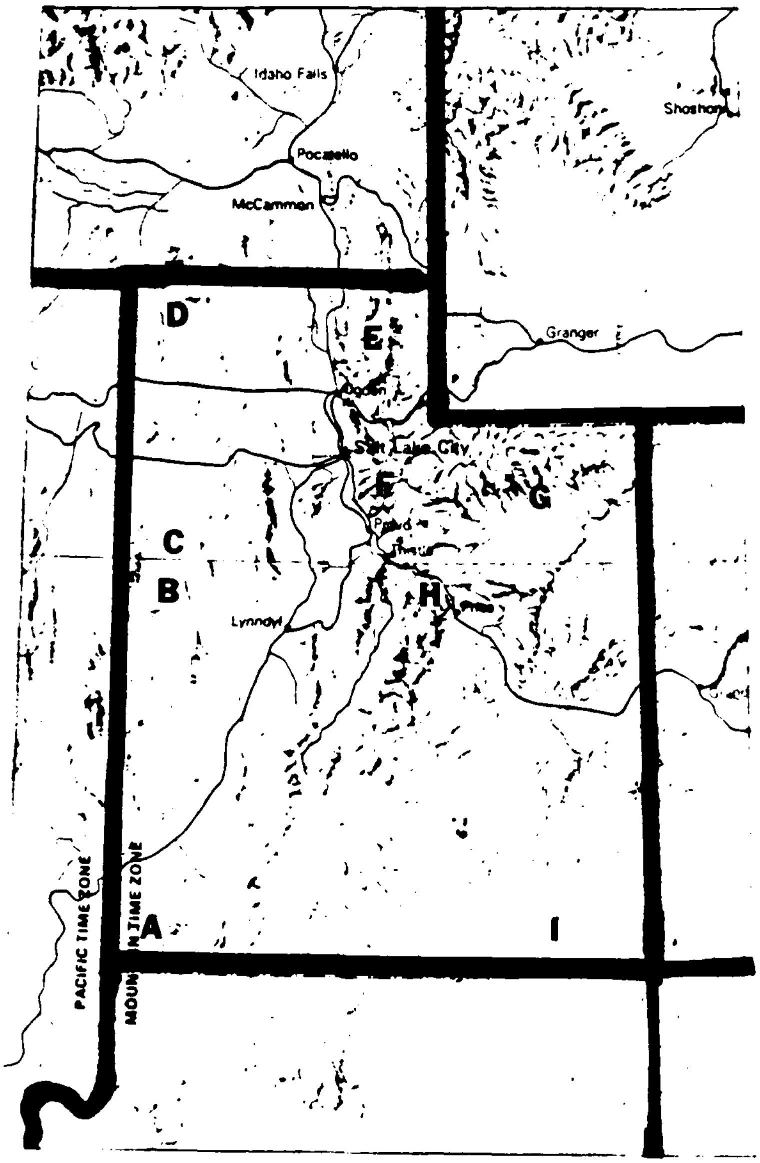


1	DUCK EGAN BERRY PONY UPPER	2	CONNER SCC HORSE	3	CITY 1 CITY 2 CITY 3	4	UINTAN
5	UINTAC UINTAD	6	NINE	7	EMERGY		

Figure 1. Tree ring locations.

Table 2. Precipitation reporting stations.

Station Name	Location				Record Length	Percent Missing
Fort Duchesne	40	17'N	109	52'W	1888-1985	1.28%
St. George	37	07'N	113	34'W	1891-1985	0.00%
Logan	41	45'N	111	48'W	1892-1985	0.00%
Heber	40	30'N	111	25'W	1893-1985	1.08%
Vernal	40	27'N	109	31'W	1895-1985	1.10%
Emery	38	55'N	111	15'W	1901-1985	3.24%
Manti	39	15'N	111	38'W	1901-1985	1.18%
Ibapah	40	02'N	113	59'W	1903-1985	7.03%
Park Valley	41	48'N	113	20'W	1911-1985	2.00%
Hiawatha	39	29'N	111	01'W	1917-1985	2.42%
Mexican Hat	37	09'N	109	52'W	1946-1985	1.88%



A	St. George	B	Garrison	C	Ibapah
D	Park Valley	E	Logan	F	Heber
G	Ft. Duchesne Vernal	H	Hiawatha Manti Emergy	I	Mexican Hat

Figure 2. Precipitation station locations.

Table 3. Tree ring - precipitation regression pairings.

Tree Ring Site	Precipitation Station	Record Length
UINTAD	Fort Duchesne	1888-1971 (84)
PONY	Ibapah	1903-1983 (81)
CONNER	Ibapha	1903-1982 (80)
NINE	Fort Duchesne	1888-1964 (77)
UINTAN	Vernal	1895-1971 (77)
UINTAC	Vernal	1895-1971 (77)
HORSE	Ibapah	1903-1978 (76)
SCC	Ibapah	1903-1978 (76)
UPPER	Ibapah	1903-1976 (74)
DUCK	Ibapah	1903-1976 (74)
EGAN	Ibapah	1903-1976 (74)
BERRY	Ibapah	1903-1976 (74)
CITY1	Park Valley	1911-1980 (70)
CITY2	Park Valley	1911-1980 (70)
CITY3	Park Valley	1911-1979 (69)
EMERY	Manti	1901-1964 (65)
NINE	Hiawatha	1917-1964 (48)

The regression equation currently used in correlating precipitation to tree growth uses eight variables:

1. Previous June precipitation (PJUN)
2. Previous July precipitation (PJUL)
3. Previous August-September precipitation (A-S)
4. Previous October-November precipitation (O-N)
5. Previous December-current February precipitation (D-F)
6. Current March-May precipitation (M-M)
7. Current June precipitation (JUN)
8. Current July precipitation (JUL)

The statistical method bootstrap was used in this regression. This procedure is used when the number of regressors is relatively large compared to the number of data points. In working with trees and precipitation, there are eight predictors, and in some cases as little as 30 years of data. Bootstrap involves repeated calculations of the same regression equation with data randomly selected, with replacement, from the entire set. For example, if 80 years of precipitation values and tree indices are regressed, 80 data lines would be selected, with replacement. Thus a typical bootstrap run might contain Year One three times, Year Two once, Year Three two times, Year Four not at all, etc., until 80 lines of data are selected. After hundreds of such runs, the coefficients of each of the regression terms would have their own distribution populations. The best estimate for each coefficient is obtained by averaging its own population, and the standard deviation of the population helps define the limits

of variability of the coefficients. Five hundred bootstrap calculations were performed on each regression equation.

Precipitation values were also regressed on Great Salt Lake water levels. Precipitation data were regressed on both yearly Salt Lake values and a ten year running mean of GSL water levels.

Finally, tree ring indices were regressed on yearly lake levels, pristine levels and modified lake levels. This allowed the Great Salt Lake water level to be reconstructed.

RESULTS AND DISCUSSIONS

Tree Ring Site Correlations

The results of the all-possible correlations were mixed. With 287 observations in each correlation (1690 - 1976, inclusive), any correlation value of .10 or greater is significantly different from zero with a one-sided test at the 95% level, and a value of .71 shows the sites contain half of the climatic signal. Table 4 shows the results of all possible correlations.

Of note are the high correlation values between CITY1, CITY2 and CITY3. Though CITY1 and CITY2 were sampled at the same time, and cover identical time periods (1120 - 1980), they do not correlate as well together as each separately correlates to CITY3, whose record length is only one-third as long (1700 - 1979). This is an indication of how well the indexing technique works. Since the index is a measure of how much a tree grows in one year with respect to how much the tree grows during its lifetime, it would be natural to assume better correlations would result from comparing two tree stands of approximately the same age, which have been exposed to nearly the same climatic events. Periods of drought, for example, would cause the trees to produce smaller rings, which in turn would affect the entire scale of the growth pattern. Subsequent periods of copious precipitation would allow the rings produced during such periods to appear larger by comparison, and thus these years would have comparitively larger index values. In other words, the average tree growth would be lowered by

Table 4. Correlation of tree ring indices.

	BERRY	SCC	EMERY	NINE	UINTAC	UINTAD	UINTAN	CITY1
SCC	.207							
EMERY	.352	.130						
NINE	.313	.087*	.370					
UINTAC	.481	.117	.291	.495				
UINTAD	.502	.138	.422	.461	.794			
UINTAN	.291	.120	.360	.291	.450	.364		
CITY1	.217	.106	.302	.392	.313	.345	.373	
CITY2	.322	.164	.195	.255	.403	.410	.425	.781
CITY3	.347	.140	.254	.030	.371	.430	.434	.814
CONNER	.760	.111	.409	.409	.536	.564	.288	.276
DUCK	.770	.064*	.332	.321	.328	.388	.265	.268
EGAN	.760	.154	.367	.369	.488	.505	.201	.235
PONY	.772	.172	.356	.274	.471	.505	.255	.247
UPPER	.457	.178	.276	.198	.327	.302	.441	.342
HORSE	.699	.203	.396	.421	.506	.557	.350	.275

* Not statistically significant at the 95% level.

Table 4. (Continued)

	CITY2	CITY3	CONNER	DUCK	EGAN	PONY	UPPER
CITY3	.947						
CONNER	.345	.365					
DUCK	.285	.332	.731				
EGAN	.290	.305	.684	.664			
PONY	.349	.356	.710	.696	.746		
UPPER	.433	.416	.435	.424	.397	.459	
HORSE	.203	.375	.777	.675	.662	.682	.410

the low values obtained during dry periods, allowing the maximum tree growth to appear more important.

Consider another tree, too young to have experienced the drought in this example, but old enough to have been influenced by the subsequent periods of plentiful moisture. One would expect the rings produced when water was abundant to be larger than average, but not as large by comparison with its life cycle as those produced, at the same time, by the trees which had experienced both drought and abundance. Since this latter tree had not experienced periods of water stress, its average growth would be higher, so the maximum values from wet periods would not appear as important.

However, the values from the three sites near City of Rocks show this is not necessarily the case. The correlations between CITY2 and CITY3 (.947) and CITY1 and CITY3 (.814) are considerably higher than between CITY 1 and CITY 2 (.781). These values indicate less than 61% of the climatic signal is shared between CITY1 and CITY2, while as much as 90% is common to both CITY2 and CITY3. The obvious question is, Why the apparent discrepancy between these values?

In a related manner is the discussion of how spatial separation affects correlation values. Listed in Table 5 are those correlations which contain at least 25% of the climatic signal, the percentage of the shared signal, and the separation distance in miles. As noted earlier, previous studies have shown sites within 100 miles (161 km) of each other should contain at least half of the climatic signal. As is readily apparent, while some sites did correlate well, by no means did all sites within 100 miles give correlation values of .71

Table 5. Tree ring sites with 25% or more common signal.

Tree Ring Sites		Percent Shared Signal (R Squared)	Separation (miles)
CITY2	CITY3	89.7%	< 1.0
CITY1	CITY3	66.2%	< 1.0
UINTAC	UINTAD	63.0%	3.0
CITY1	CITY2	60.9%	< 1.0
CONNER	HORSE	60.4%	41.4
BERRY	PONY	59.6%	18.7
BERRY	DUCK	59.3%	3.3
BERRY	CONNER	57.8%	21.5
BERRY	EGAN	57.8%	57.8
EGAN	PONY	55.7%	24.4
CONNER	DUCK	53.4%	23.8
CONNER	PONY	50.4%	47.0
BERRY	HORSE	48.9%	62.9
DUCK	PONY	48.4%	30.8
CONNER	EGAN	46.8%	31.4
PONY	HORSE	46.5%	51.1
DUCK	HORSE	45.6%	45.6
DUCK	EGAN	44.1%	13.3
EGAN	HORSE	43.8%	62.8
UINTAD	CONNER	31.8%	376.2
UINTAD	HORSE	31.0%	334.9
UINTAC	CONNER	28.7%	375.5
UINTAC	HORSE	25.6%	334.2
UINTAD	EGAN	25.5%	394.6
UINTAD	PONY	25.5%	366.8
UINTAD	BERRY	25.2%	379.3

or greater (= 50% shared signal). EMERY and NINE are separated by approximately 93 miles, but share only about 14% of the same signal. NINE is also within 75 miles of the three sites in the Uinta Mountains, but the best value is only 24%.

More surprising is the correlation between the Uinta Mountain sites. While UINTAC and UINTAD have 63% of the signal in common, they share only 20% and 13%, respectively, with UINTAN, only some 40 miles distant.

By far the poorest showings are from the UPPER and SCC sites. These two sites failed to show a correlation corresponding to even a 25% common signal, though they were relatively close to several stations. UPPER is within 45 miles of 7 other stations in eastern Nevada, but shares at best only 21%, with PONY. A mere 1.6 miles separate SCC and HORSE, but they have only 4% of the climatic signal in common.

On the other hand, there are six pairs, separated by more than three hundred miles, which share at least 25% of the signal. This includes the UINTAD and EGAN, which are separated by nearly four hundred miles, and are the furthest pairing in this study. Such a situation begs the question, 'If this pair can share that much signal, why should the others have so little in common?'

One of the underlying assumptions of this study has been, while precipitation varies between sites, all other factors are constant. While it is true available water is generally the most limiting factor in tree growth, other factors can contribute greatly. Such things as pest infestation, environmental pollution, slope of site with respect

to level ground or other microsite conditions could well cause variation in growth. For example, cloud formation over the Uinta Mountains due to orographic lifting in the summer would decrease the amount of solar radiation, in turn limiting photosynthesis. Such conditions could well account for the discrepancies in growth between UINTAN, located in the mountains and DUCK, in the eastern Nevada desert, where the sun shines almost continually during the summer. Since storms do not come from random directions, attitude towards predominant storm tracks is also very important. Western facing slopes will pick up more precipitation throughout the year than will eastern slopes. Northern slopes will collect more precipitation during the winter than they will during the summer, since winter storms come from the north. Just the opposite happens to southern slopes. Summer storms come from the south, depositing most of their moisture on the south facing slopes. Microsite climatic factors, then, are at least as important as larger scale synoptic conditions.

Thus, while almost all of the stations showed significant correlation with each other, and some correlated very well with nearby sites, while others shared a relatively high amount of common signal over a large distance, there is no conclusive evidence to support the earlier studies. Not only do all sites within 100 miles not share 50% of the common signal, sites much closer may not even share half that value.

Past studies of this nature were done primarily in the Four Corners area, Arizona and New Mexico. The terrain is relatively uniform there, and precipitation falling in these areas can also be assumed

uniform. In contrast, the tree sites used in this study come from both low lying and mountainous areas. These orographic features greatly affect the synoptic storm systems which pass through Nevada, Idaho and Utah. The same storm can deposit large amounts of precipitation in the mountains, and little or none in lower areas. As mentioned earlier, storm tracks will influence which sides of mountains will gather more mositure. This is the major factor influencing these correlations. While precipitation patterns can be considered uniform in areas where the terrain is uniform, the terrain features in the area of this study cannot be ignored. The influences of orographicly produced cloud cover, precipitation, and attitude of tree stand with respect to synoptic storm tracks are of primary importance. Their effects overshadow simple linear separation in the correlation of tree sites.

Regression of Precipitation Data on Tree Ring Indices

The regression equation used has eight variables: previous year's June precipitation; previous July precipitation; previous August-September; previous October-November; previous December through current February; current March-May; current June; and current July. Bootstrap was used on these regressions, to get an estimate of both the coefficients for the regression terms, and standard deviations of those coefficients.

Previous studies have found good correlations between tree sites and precipitation records from stations approximately 20 miles (32 km) away. Unfortunately, the stations in this study were located further,

and in some cases considerably further from the tree ring sites. The distances between the sites and the stations are listed in Table 6, as well as the coefficients from the regression equation for both the bootstrap and full data models. Also listed are the R squared values from the full data runs and the standard deviation of the coefficients from the bootstrap runs.

For this part of the research only, another precipitation station was added. Since some of the distances between the eastern Nevada stations and Ibapah were so large, data from Garrison, Utah, were also regressed and bootstrapped. Garrison, located in western Utah (38 56'N, 114 02'W), has a data set which covers the period from the early 1900s to 1985, but 44% of the data is missing. Since most of the missing data is in the first half of the century, the regressions were run from 1952 on.

The most surprising result of these regressions is the high frequency of negative correlations, especially in previous July and August-September values. More than half of the 23 regressions showed a negative correlation with previous July data. All but one of the stations regressed with Garrison had negative correlations with previous July. A possible explanation is that the lack of appreciable rainfall in this area leads to statistical importance by practical non-importance. In this part of the country, at this time of the year, the regression model may break down because of the extreme lack of moisture, leading to spurious results.

Another odd correlation is between all the sites in the Uinta Mountains and previous June precipitation. The coefficients were all

Table 6. Tree ring - precipitation site regression results.

Tree Ring Site	Precipitation Station	R Squared Value	Distance
	Total Data	Bootstrap	St. Deviation
Intercept Previous June Previous July August-September October-November December-February March-May June July			
UINTAD	Fort Duchesne	1888 - 1971	23.5%	28 miles
	Total Data	Bootstrap	St. Deviation
Intercept	0.5931	0.6163	0.1265
PJUN	-0.8638	-0.9427	0.4981
PJUL	1.0080	0.9200	0.0811
A-S	0.0698	0.0323	0.0623
O-N	0.0869	0.0915	0.0343
D-F	0.0696	0.0670	0.0308
M-M	0.0542	0.0558	0.0316
JUN	0.0570	0.0511	0.0492
JUL	0.0728	0.0624	0.0803
PONY	Ibapah	1903 - 1983	29.3%	53 miles
	Total Data	Bootstrap	St. Deviation
Intercept	0.5877	0.6029	0.0947
PJUN	0.0413	0.0393	0.0323
PJUL	0.0357	0.0361	0.0609
A-S	-0.0164	-0.0148	0.0324
O-N	0.0024	0.0024	0.0343
D-F	0.0075	0.0084	0.0291
M-M	0.0645	0.0612	0.0156
JUN	0.0458	0.0384	0.0279
JUL	0.1118	0.1208	0.0469

Table 6. (Continued)

CONNER	Ibapah	1903 - 1982	16.8%	106 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.7488	0.1114	0.0947	
PJUN	0.0154	0.0230	0.0379	
PJUL	-0.0168	-0.0165	0.0502	
A-S	0.0346	0.0394	0.0331	
O-N	-0.0204	-0.0294	0.0346	
D-F	-0.0066	0.0091	0.0373	
M-M	0.0467	0.0468	0.0220	
JUN	0.0528	0.0623	0.0299	
JUL	0.0860	0.0836	0.0524	
CONNER	Garrison	1952 - 1982	32.4%	42 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	1.1853	1.7470	1.1040	
PJUN	0.1224	0.1185	0.0584	
PJUL	-0.1033	-0.0601	0.1307	
A-S	0.0254	0.0261	0.0504	
O-N	-0.0704	-0.0852	0.0424	
D-F	-0.0928	0.0973	0.0501	
M-M	-0.0286	-0.0316	0.0149	
JUN	0.0039	0.0174	0.0823	
JUL	0.1984	0.1977	0.0793	
NINE	Fort Duchesne	1888 - 1964	39.0%	60 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.4648	0.4781	0.1828	
PJUN	0.1299	0.1148	0.0563	
PJUL	0.1462	0.1070	0.0915	
A-S	0.0464	0.0461	0.0448	
O-N	0.2255	0.2217	0.0410	
D-F	0.1024	0.1105	0.0489	
M-M	0.0568	0.0654	0.0530	
JUN	0.0101	0.0020	0.0579	
JUL	0.0014	-0.0214	0.0886	

Table 6. (Continued)

NINE	Hiawatha	1917 - 1964	40.0%	63 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.6105	0.5693	0.2325	
PJUN	0.1029	0.1151	0.0405	
PJUL	-0.1434	-0.0035	0.0642	
A-S	0.0258	0.0285	0.0255	
O-N	0.0376	0.0461	0.0261	
D-F	0.1183	0.1118	0.0254	
M-M	0.0744	0.0721	0.0222	
JUN	-0.0125	0.0115	0.0414	
JUL	-0.0639	0.0557	0.0516	
UINTAN	Vernal	1895 - 1971	15.4%	89 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.9909	0.9774	0.0717	
PJUN	-0.0795	-0.0752	0.0297	
PJUL	0.0484	0.0519	0.0411	
A-S	0.0118	0.0233	0.0209	
O-N	0.0309	0.0301	0.0191	
D-F	-0.0102	-0.0145	0.0238	
M-M	-0.0018	0.0060	0.0159	
JUN	-0.0216	-0.0158	0.0258	
JUL	0.0489	0.0375	0.0432	
UINTAC	Vernal	1895 - 1971	32.9%	34 miles
	Total Data	Bootstrap	St, Deviation	
Intercept	0.6824	0.7031	0.1909	
PJUN	-0.2436	-0.2539	0.0592	
PJUL	0.1884	0.1824	0.1368	
A-S	0.1244	0.1205	0.0593	
O-N	0.0642	0.0537	0.0465	
D-F	0.0456	0.0548	0.0547	
M-M	-0.0188	-0.0141	0.0341	
JUN	-0.0968	-0.0966	0.0725	
JUL	0.0280	0.1114	0.2654	

Table 6. (Continued)

HORSE	Ibapah	1903 - 1978	30.6%	60 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.4775	0.4643	0.1264	
PJUN	0.0519	0.0515	0.0340	
PJUL	0.0202	0.0213	0.0618	
A-S	0.0158	0.0189	0.0397	
O-N	0.0123	0.0119	0.0399	
D-F	-0.0529	0.0430	0.0351	
M-M	0.1125	0.1098	0.0211	
JUN	0.0273	0.0335	0.0457	
JUL	0.1127	0.1093	0.0660	
HORSE	Garrison	1952 - 1978	32.1%	28 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	1.0953	1.1067	0.0677	
PJUN	0.0854	0.0816	0.0402	
PJUL	-0.0424	-0.0319	0.0528	
A-S	-0.0280	-0.0317	0.0437	
O-N	-0.0464	-0.0479	0.0316	
D-F	-0.0994	-1.3870	0.0400	
M-M	-0.0331	-0.0331	0.0124	
JUN	0.1080	0.1111	0.0586	
JUL	0.0542	0.0534	0.0605	
SCC	Ibapah	1903 - 1978	5.2%	60 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.8953	0.8724	0.1364	
PJUN	0.0075	0.0082	0.0472	
PJUL	-0.0009	-0.0052	0.1030	
A-S	0.0332	0.0428	0.0512	
O-N	0.0586	0.0650	0.0832	
D-F	0.0170	0.2350	0.0075	
M-M	0.0106	0.0042	0.0285	
JUN	-0.0176	0.0022	0.0729	
JUL	-0.0564	0.0529	0.0914	

Table 6. (Continued)

SCC	Garrison	1952 - 1978	24.5%	42 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.7766	0.7514	0.0793	
PJUN	0.1683	0.1859	0.0551	
PJUL	-0.1468	-0.1692	0.0483	
A-S	-0.0087	-0.0032	0.0295	
O-N	0.0661	0.0626	0.0362	
D-F	-0.0147	-0.0100	0.0354	
M-M	0.0146	0.0182	0.0115	
JUN	0.1411	0.1318	0.0421	
JUL	-0.1390	-0.1322	0.0630	
UPPER	Ibapah	1903 - 1976	13.6%	82 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.8058	0.7970	0.0924	
PJUN	0.0404	0.0426	0.0299	
PJUL	0.0598	0.0683	0.0455	
A-S	-0.0097	-0.0054	0.0214	
O-N	0.0206	0.0154	0.0267	
D-F	0.0199	0.0187	0.0205	
M-M	0.0018	-0.0005	0.0199	
JUN	0.0292	0.0303	0.0281	
JUL	0.0205	0.0229	0.0313	
UPPER	Garrison	1952 - 1976	37.0%	70 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	1.0476	1.4220	0.0337	
PJUN	0.0436	0.0375	0.0593	
PJUL	0.0394	0.0453	0.0438	
A-S	-0.0663	-0.0654	0.0255	
O-N	-0.0357	-0.0330	0.0159	
D-F	0.0034	0.0021	0.0362	
M-M	-0.0181	-0.0269	0.0069	
JUN	-0.0311	-0.0269	0.0538	
JUL	0.1050	0.0997	0.0346	

Table 6. (Continued)

DUCK	Ibapah	1903 - 1976	17.8%	121 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.7751	0.7766	0.1083	
PJUN	0.1056	0.1058	0.0359	
PJUL	-0.0557	-0.0707	0.0568	
A-S	0.0637	0.0759	0.0313	
O-N	-0.0054	-0.0122	0.0437	
D-F	-0.0441	-0.0489	0.0407	
M-M	0.0247	0.0281	0.0272	
JUN	0.0916	0.0839	0.0413	
JUL	0.0158	0.0152	0.0763	
DUCK	Garrison	1952 - 1976	29.0%	70 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	1.0831	1.0210	0.1145	
PJUN	0.2156	0.2188	0.0893	
PJUL	-0.1474	-0.1495	0.0876	
A-S	-0.0103	-0.0017	0.0373	
O-N	0.0129	0.0045	0.0516	
D-F	-0.0476	-0.0517	0.0596	
M-M	-0.0339	-0.0375	0.0148	
JUN	0.1006	0.0916	0.0901	
JUL	0.0852	1.0469	0.0608	
EGAN	Ibapah	1903 - 1976	33.8%	100 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.4875	0.4667	0.1071	
PJUN	0.0042	0.0010	0.0307	
PJUL	0.0808	0.0851	0.0556	
A-S	-0.0615	-0.0590	0.0366	
O-N	-0.0323	-0.0256	0.0328	
D-F	0.0543	0.0525	0.0277	
M-M	0.0844	0.0886	0.0208	
JUN	1.0771	1.0789	0.0420	
JUL	1.1611	1.1322	0.0411	

Table 6. (Continued)

BERRY	Ibapah	1903 - 1976	29.8%	89 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.4989	0.4911	0.1116	
PJUN	0.0566	0.0520	0.0329	
PJUL	0.0434	0.0422	0.0720	
A-S	-0.0186	-0.0213	0.0407	
O-N	0.0312	0.0352	0.0360	
D-F	0.0502	0.0122	0.0408	
M-M	0.0590	0.0575	0.0199	
JUN	0.0781	0.0801	0.0392	
JUL	1.1495	1.2313	0.5883	
BERRY	Garrison	1952 - 1976	37.1%	70 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	1.0117	1.0191	0.0685	
PJUN	0.0407	0.0280	0.0502	
PJUL	-0.0407	-0.0159	0.0815	
A-S	0.0302	0.0294	0.0359	
O-N	-0.0633	-0.0646	0.0352	
D-F	-0.1493	-0.1548	0.0429	
M-M	0.0025	0.0047	0.0114	
JUN	0.1004	0.1078	0.0591	
JUL	0.0641	0.0582	0.0092	
CITY1	Park Valley	1911 - 1980	30.7%	42 miles
	Total Data	Bootstrap	St.Deviation	
Intercept	0.7431	0.7477	0.1508	
PJUN	0.0651	0.0613	0.0319	
PJUL	-0.0376	-0.0343	0.0333	
A-S	0.0606	0.0613	0.0237	
O-N	0.0187	0.0210	0.0310	
D-F	0.0454	0.0430	0.0297	
M-M	0.0431	0.0388	0.0239	
JUN	0.0813	0.0853	0.0266	
JUL	0.0270	0.0297	0.0303	

Table 6. (Continued)

CITY2	Park Valley	1911 - 1980	29.8%	42 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.6272	0.6606	0.0973	
PJUN	0.0368	0.0356	0.0284	
PJUL	-0.0283	-0.0330	0.0295	
A-S	0.0436	0.0464	0.0229	
O-N	0.0268	0.0159	0.0186	
D-F	0.0397	0.0301	0.0211	
M-M	0.2222	0.0251	0.0149	
JUN	0.0732	0.0712	0.0308	
JUL	0.2266	0.0314	0.2920	
CITY3	Park Valley	1911 - 1979	25.2%	42 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.7371	0.7363	0.1147	
PJUN	0.0647	0.0673	0.0279	
PJUL	-0.0179	-0.0168	0.0279	
A-S	0.3936	0.0458	0.0217	
O-N	0.0088	0.0020	0.0209	
D-F	0.0193	0.0137	0.0259	
M-M	0.0258	0.0258	0.0134	
JUN	0.0515	0.0583	0.0231	
JUL	0.0248	0.0300	0.0288	
EMERY	Manti	1901 - 1964	28.1%	37 miles
	Total Data	Bootstrap	St. Deviation	
Intercept	0.7895	0.7858	0.1325	
PJUN	0.0595	0.0534	0.0377	
PJUL	-0.0125	-0.2204	0.0344	
A-S	0.0577	0.0479	0.0289	
O-N	0.0163	0.0195	0.0231	
D-F	0.0491	0.0505	0.0228	
M-M	0.0019	0.0032	0.0150	
JUN	0.0784	0.0793	0.0284	
JUL	0.0037	0.0105	0.0295	

relatively high, and all three were negative. Why previous summertime precipitation would correlate negatively is not apparent.

Average distance for the 17 best fit cases was 45.8 miles, and average R squared values is 29%, while for all 23 cases, R squared was 26%, for an average distance of 49.1 miles. It would be easy to then draw a distance to R squared relationship, but since one of the best correlations was between EGAN and Ibapah (30.7%), which are 82.6 miles away from each other, and the worst was between SCC and Ibapah (5.2%) which are 46.5 miles apart, anything more than a general conclusion would be highly questionable. Furthermore, the few site-station pairings separated by less than 30 miles did not show significantly better R squared values than did the other pairs. Of the three pairs with a separation of less than 30 miles, only one had an R squared value of better than 30%, while 5 pairings of 50 miles or more had at least a 30% R squared value. Overall, it is safe to say there is at least a casual relationship between distance and correlation, but to state site A will correlate better with precipitation station B than will site C, simply because A and B are closer than are B and C is not supported by this study.

Once again, the cause for the low correlation values appears to be due to discrepancies between precipitation collected at weather stations and actual amounts falling in the remote tree site locations. Terrain effects are again important. Most precipitatation gathering stations are located in relatively high population centers, which are generally at lower elevations than are the tree sites. Precipitation amounts increase with increasing elevation, for the most part, and this

increase is not linear. Also, differences in attitude between tree sites and weather stations are even more important for this correlation than for between tree site correlations. In the previous section, only yearly growth, and thus total yearly precipitation values, were being compared. Now, the precipitation records are broken into periods as short as one month. A weather station facing south during the summer may pick up several inches of precipitation, while a tree site only a few miles away, but sitting on the sheltered north face of a mountain, would receive only a fraction of that amount. Again, terrain features in the mountainous area of this study, and their orographic effects on weather, overshadow the influence of spatial separation, and tend to diminish its importance.

The model used in this regression is standard for tree ring analysis in the western United States. However, the area of this study contains sites which have almost no precipitation during the summer, specifically the eastern Nevada sites, and mountainous regions which pick up most of their precipitation during the winter. Both of these factors tend to denegrate the model. Work in plant physiology in the geoclimatic regimes of the western US should be done, to determine better relationships between precipitation and tree growth.

The bootstrap analysis provided a second set of coefficients for each regression equation as well as a standard deviation for those coefficient values. In only one case (O-N of the DUCK-Ibapah pairing) did the coefficient from the total data run fall more than one standard deviation away from the bootstrap value. This may account for the low R squared value of this pairing.

In all, the results of these regressions were disappointing. Most of the problem is the result of an uncontrollable factor; precipitation gathering locations are located in more urbanized areas, while the best tree ring data are taken in remote locations. The two are usually separated by a large distance, and this leads to great variations in precipitation, due to both the spatial separation and differences in terrain and attitude toward preferred storm tracks.

A second limitation of this method is it uses only precipitation. In this study precipitation is the major concern, since it directly forces rises and falls in the Great Salt Lake. But from a purely dendroclimatic viewpoint other factors should be added to the regression equation, and this could be done without making the equation unwieldy. Since even the most primitive climatic records usually contain both precipitation and temperature observations, temperature at the minimum could be worked into the equation. More complete models could use a combination of the two, a useable water term, which takes into account latent heat fluxes.

Precipitation Regression on the Great Salt Lake

The drainage basin for the Great Salt Lake lies primarily to the north and northeast of the lake. To the east and south, drainage is primarily to the Colorado River, principally through the Green River. Precipitation falling to the west will slowly move east, but most of it is absorbed into the water table.

The 11 precipitation stations were regressed on both the yearly maximum values of Great Salt Lake depth, and a ten year running mean of maximum values. The results are listed in Table 7.

Table 7. Precipitation regression on the Great Salt Lake.

Precipitation Station	Annual	10 Year Average
Intercept	4196.0	4197.0
Emery	0.2449	0.2287
Fort Duchesne	-0.3248	-0.0378
Vernal	0.3609	0.1805
Mexican Hat	0.1306	0.2774
St. George	0.5104	0.3141
Ibapah	-0.3173	-0.0594
Park Valley	-0.1004	0.2546
Hiawatha	-0.3780	-0.2958
Logan	0.3552	-0.0519
Heber	-0.0247	-0.2080
Manti	-0.1667	0.2119
R Squared	47%	49%

Once again, negative correlation coefficient values pose a problem in analyzing the findings. In the annual maximum case, the situation is less complex. Positive correlations with Emergy, St. George, Mexican Hat, Vernal and Logan show a reasonable south west to north east pattern. The logical conclusion is, synoptic weather systems associated with subtropical moisture from the Baja region of California which flow through this area deposit precipitation in the Great Salt Lake drainage basin which affects lake levels. Storms which travel to the northeast, but further west drop their moisture along a line between the Park Valley and Ibapah stations. This moisture cannot easily reach the Salt Lake, and accounts for the negative correlations.

Fort Duchesne lies within the preferred storm track, yet correlates negatively. A probable cause is the storm intensity. Both Fort Duchesne and Vernal lie in the Uinta Mountains, with Vernal north west of Fort Duchesne. Due to orographic lifting precipitation from north east tracking storms should begin earlier at Fort Duchesne. Weak storms would drop most of their precipitation then on the south slope of the Uintas, which run east-west. Since both Vernal and Fort Duchesne drain into the Green River, and then into the Colorado, precipitation which falls there does not directly influence Great Salt Lake levels. But strong storms would carry precipitation further north into areas which do drain into the Salt Lake. Thus, a negative correlation with Fort Duchesne would indicate precipitation from weaker storms which falls in the Green River basin and is lost to the Great Salt Lake. Vernal data is an indicator of stronger storms which drop their precipitation further

north, in the Salt Lake drainage basin, and which will affect the level of the lake.

Two other stations, Manti and Heber, also fall into the preferred storm track and have negative correlation values, but their values are so small, only between 6% to 30% of the others, that they can be neglected.

Regressions on the ten year average yielded similar results. Most stations which correlated negatively previously still have negative correlation coefficients. The major discrepancy is with Logan. Logan, which had correlated positively now is negative, but the value is so small as to be negligible.

Overall, a slightly better correlation was found between average maximum depths than with annual maximums (R squared values 49% and 47%, respectively). This difference could be important in future studies, and researchers use both procedures.

Previous studies have shown mediocre R squared values when precipitation records were regressed on lake levels, and only slightly better results were gained in this study. The main problem appears to be in the density and placement of recording stations. More weather stations would improve this situation, but they must be located purposefully. As alluded to earlier, weather stations are located in urbanized areas at low elevations, while most precipitations falls at high elevations, and the increase is not a simple linear function of altitude. In mountainous terrain, precipitation is not uniform. Currently, weather stations can only gather data at fixed points around the state and these sites are not representative of the total amount of precipitation which

falls in the basin. For the most part, the precipitation measured will be too low an estimate of actual precipitation. Cites are not located randomly with respect to weather conditions. They are, for the most part, located in regions protected from the severest weather, i.e. at lower elevations where precipitation, particularly winter snow, is not as heavy.

Tree Ring Regression on the Great Salt Lake

All of the tree ring sites were initially regressed on the actual Great Salt Lake level from 1851 to 1964, with a resulting R squared value of 51%. Elimination of 6 sites had a minimal effect on the R squared value, decreasing it only .9%, and this became the preferred model. Table 8 lists the tree sites and their regression coefficients. Once the best model was established, the tree ring data previous to 1851 was plugged into the equation, and the Great Salt Lake levels were reconstructed. Plotted in Figure 3 is this reconstruction. The most limiting case in terms of temporal span is SCC, whose record goes back only to 1690. The regression was rerun without SCC, and the results are also listed in Table 8. This second equation covers 80 more years, and the R squared value drops only .6%, to 49.5%. This allows the lake to be reconstructed back to 1610, as shown in Figure 4. Both reconstructed figures show considerable variation in the early years, and the amplitude of the variation decreases considerably after 1800.

Figures 5-7 show the reconstruction on a more expanded time scale. Figure 5 is a graphical representation taken from the second model, while the results of the preferred model are shown in Figures 6 and 7, from 1690 to 1850.

Table 8. Tree ring regression on the Great Salt Lake.

Tree Ring Site	Preferred Model	Second Model
Intercept	4204.00	4203.01
UINTAN	-2.990	-2.616
EMERY	-4.371	-4.482
CITY1	-14.601	-14.991
CITY2	20.704	21.160
UPPER	5.555	5.279
DUCK	-2.981	-2.375
BERRY	1.830	1.203
HORSE	3.731	3.511
PONY	-5.741	-5.531
SCC	-0.978	
R Squared	50.1%	49.5%

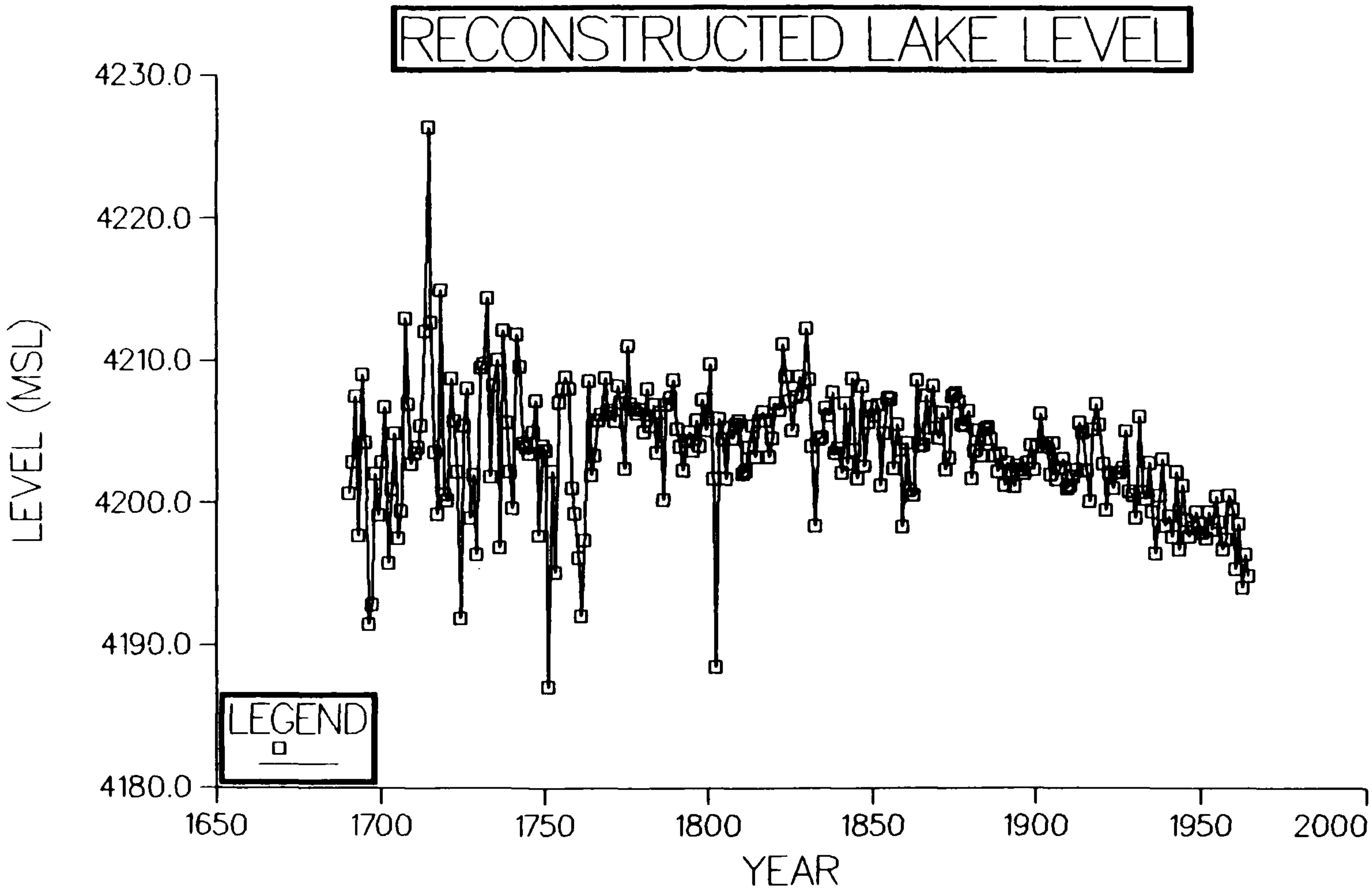


Figure 3. Reconstructed lake level (1690 - 1850).

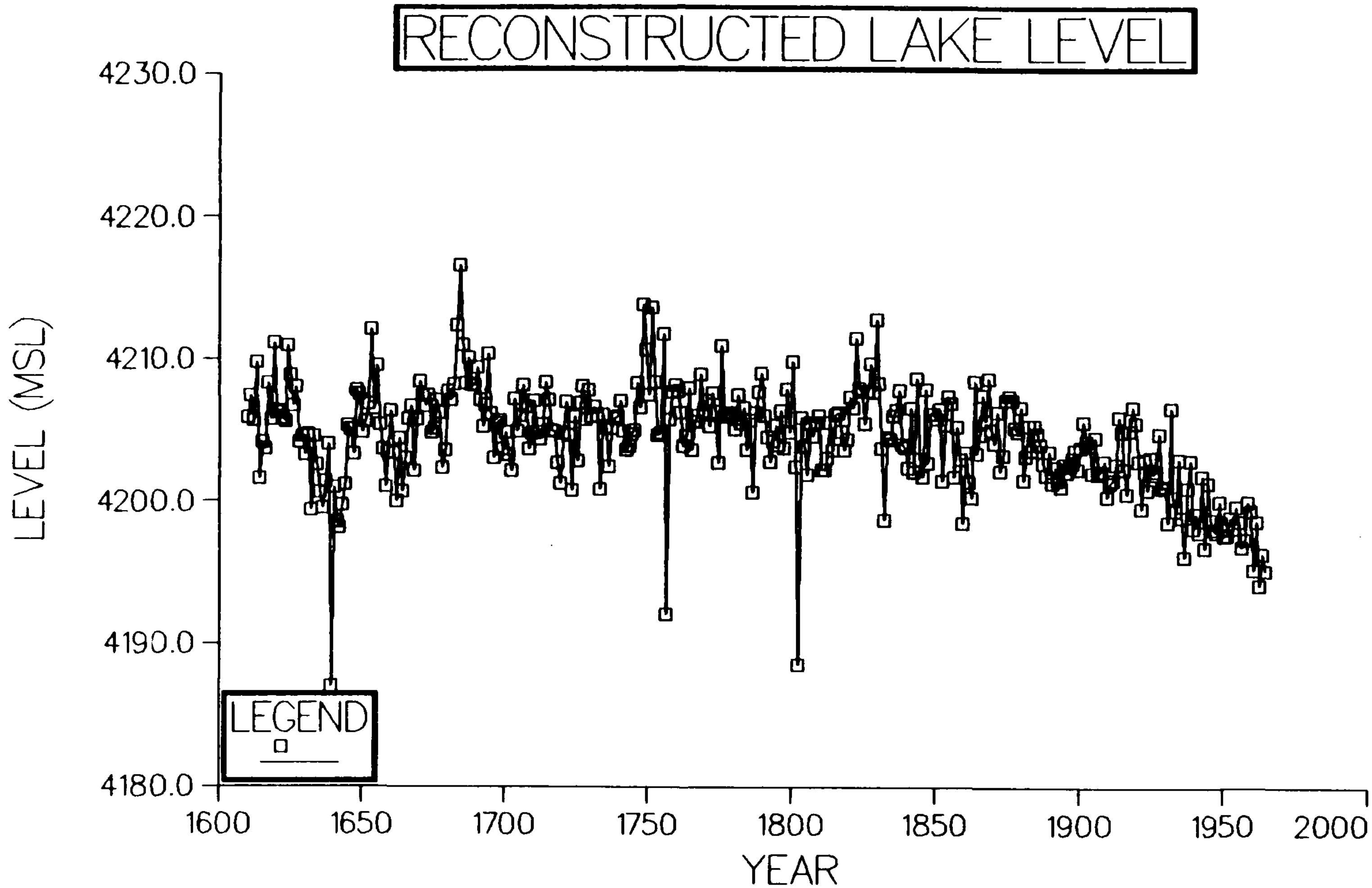


Figure 4. Reconstructed lake level (1610 - 1850).

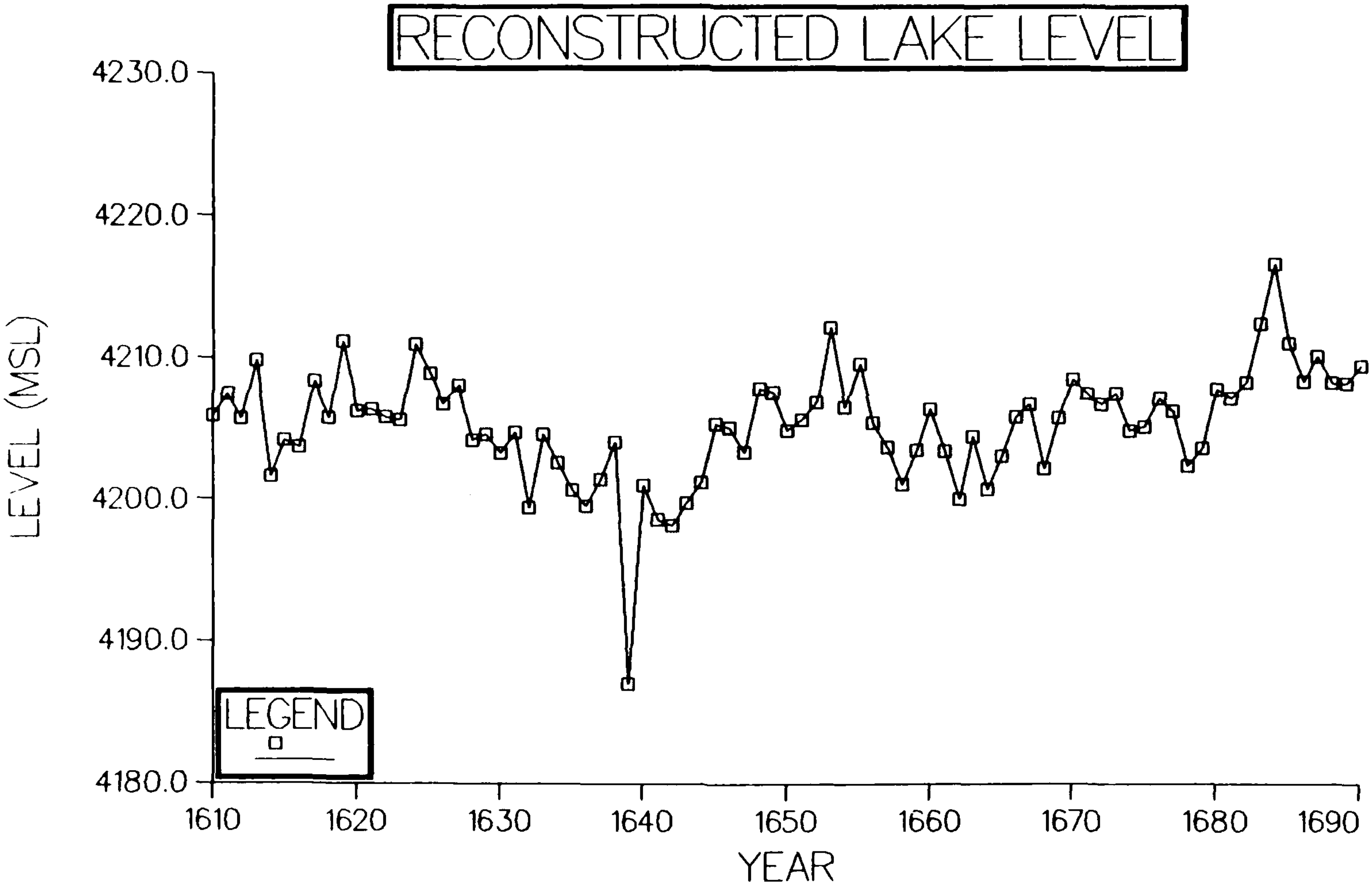


Figure 5. Reconstructed lake level (1610 - 1690).

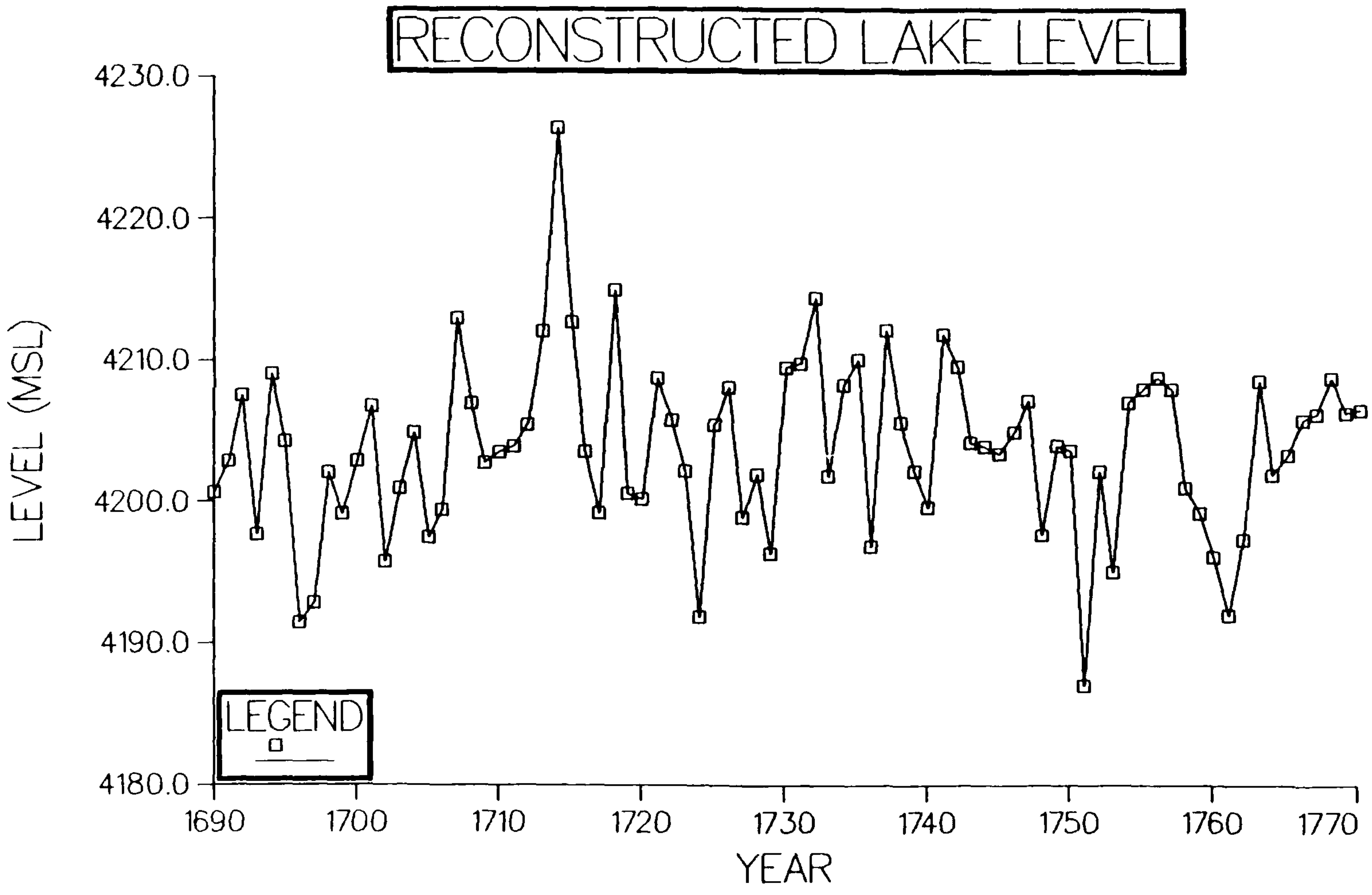


Figure 6. Reconstructed lake level (1690 - 1770).

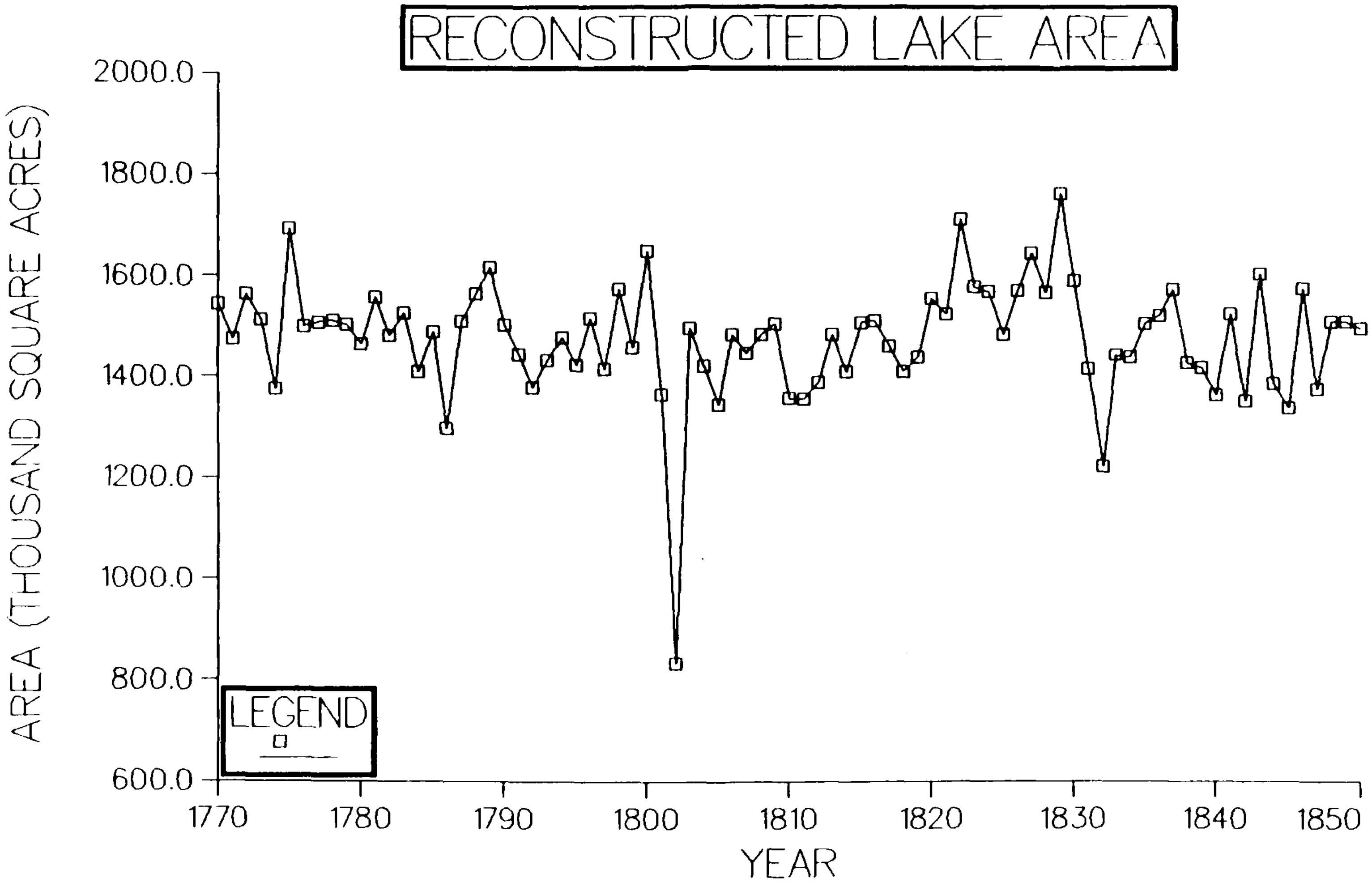


Figure 7. Reconstructed lake level (1770 - 1850).

The maximum and minimum predicted values come from the preferred model, 4226 feet MSL in the early 1700s, and 4187 in 1751. The second model is slightly more conservative, ranging from 4187 to 4217.

Though the preferred model has a slightly better R squared value, it is unlikely the lake behaved as this model predicts. The high fluctuation predicted from 1690 to the mid 1760s is unlikely at best. The second model gives a much more believable trace of predicted lake levels. While this model does not predict a value as high as the 4226 level in the preferred model, the results from the models are quite similar from the mid 1700s onward. Both predict minima around 1750 and 1800, and have relative maxima in the 1820s, the 1870s and the period 1917-1920. These last two maxima match up quite well with actual recorded lake levels. Actual Great Salt Lake levels are shown in Figure 8.

The most interesting thing about the reconstructed lake levels are how they compare with lake levels from 1851 to 1964. A comparison of model results and lake levels is shown in Table 9. Both models were more conservative than the lake. While the models fluctuated from year to year considerably more than did the Salt Lake, their maximum and minimum values were less extreme than actual conditions. During the 114 year period, the Great Salt Lake fluctuated from 4193 feet MSL to 4212 MSL. During this same period, the preferred and second models predicted values of 4194 and 4209 feet MSL. This suggests lake levels prior to 1851 could have been higher than predicted. Since both models already produce values in excess of record measurements of the Salt Lake, it is only logical to conclude the lake has previously been as high or higher than it is currently.

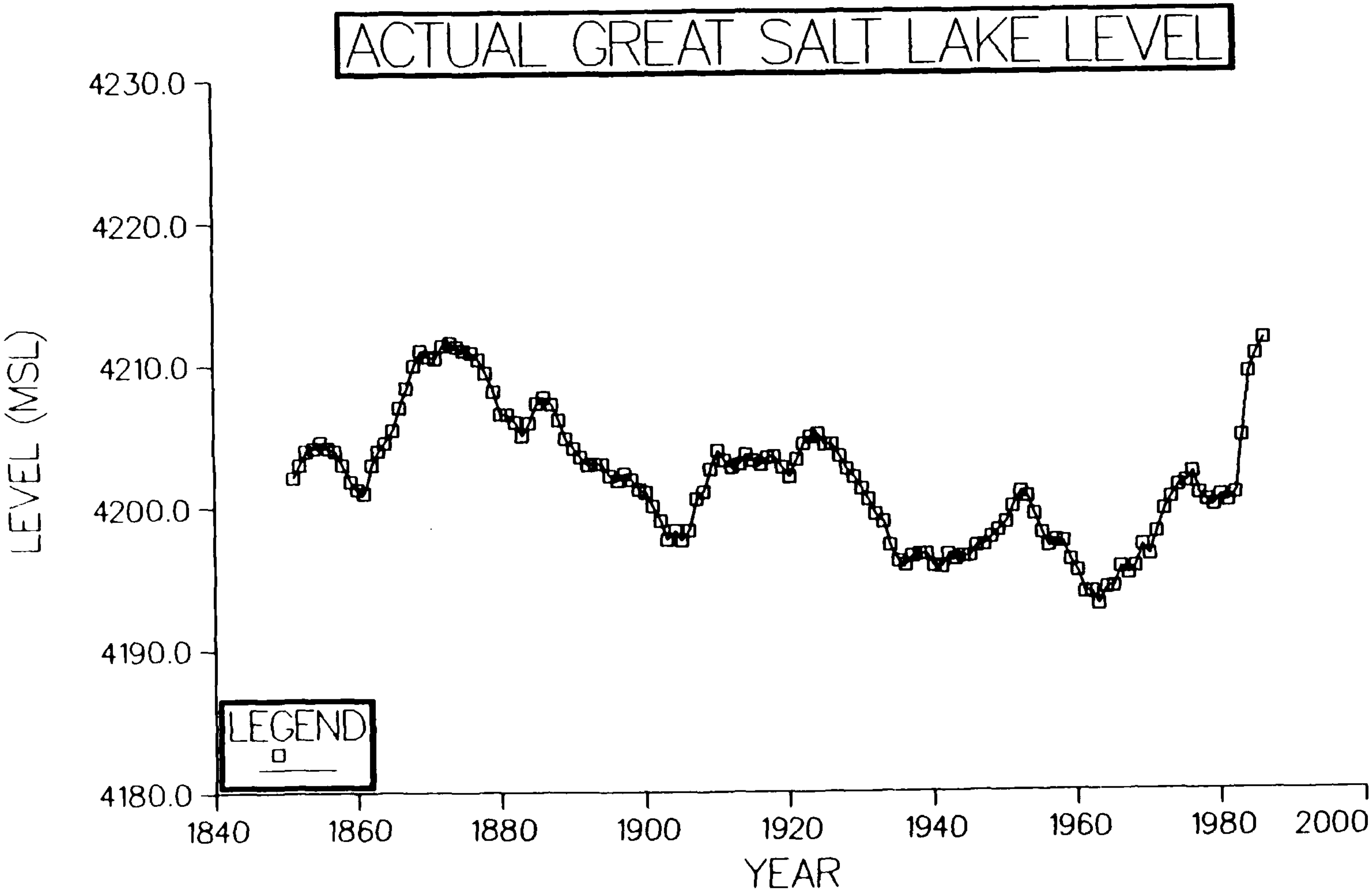


Figure 8. Actual Great Salt Lake level.

Table 9. Comparison of actual and predicted lake levels (1851-1964).

Source	Mean	Median	Minimum	Maximum	St. Dev.
Measured GSL Levels	4202.2	4202.7	4193.0	4211.6	4.5
Preferred Model	4202.2	4202.3	4194.0	4208.6	3.2
Second Model	4202.2	4202.7	4194.2	4208.7	3.2

A final consideration is the periodicity of lake fluctuations, specifically relative maximum lake levels. Two known peaks are in the 1870s and 1980s. Predicted peaks occur in the 1750s and 1690s. Four values do not constitute enough data from which to draw conclusive results, but these peaks are separated by 60, 120 and 110 years, which gives evidence of a long term variation in lake levels, with an unknown period, but probably in excess of 50 years. In addition to the large peaks, smaller relative peaks occured in the 1950s and the period 1917-1922, while relative peaks are predicted in the 1820, the 1750s and the 1650s. These peaks and relative peaks are separated by 30 to 70 years, suggesting a fluctuation with a period 40-50 years.

The tree ring sites were also regressed on two other Great Salt Lake levels, the pristine and modified. Neither of these is an actual measurement, but are estimates of the lake level based on the measurements of the Great Salt Lake. The pristine level is an estimate of what the lake would be if there had been no human activity, such as agricultural irrigation, damming of feeder rivers, etc., siphoning off water for the last 130 odd years. The modified level is the exact opposite, estimating the lake as though there had been constant human activity around the Great Salt Lake. Thus, the pristine level is greater than the measured value for the lake, while the modified level is the smallest of the three.

Results from the regression on the pristine and modified levels are shown in Table 10, and Figures 9-12 show reconstructed and actual estimates for both. Like the previous regression on measured lake levels, the reconstructed models of the lake for pristine and modified

Table 10. Regression on pristine and modified lake levels.

Tree Ring Site	Pristine Model	Modified Level
Intercept	4207.22	4196.83
CITY1	-1.566	-8.035
CITY2	4.215	12.376
CONNER	1.784	3.622
DUCK	-3.252	-3.942
EGAN	-1.748	-1.744
EMERY	-2.002	-3.240
HORSE	4.195	2.731
PONY	-2.540	-3.436
UPPER	4.964	5.437
NINE	-1.019	
UINTAN	-1.830	
R Squared	38.8%	53.0%

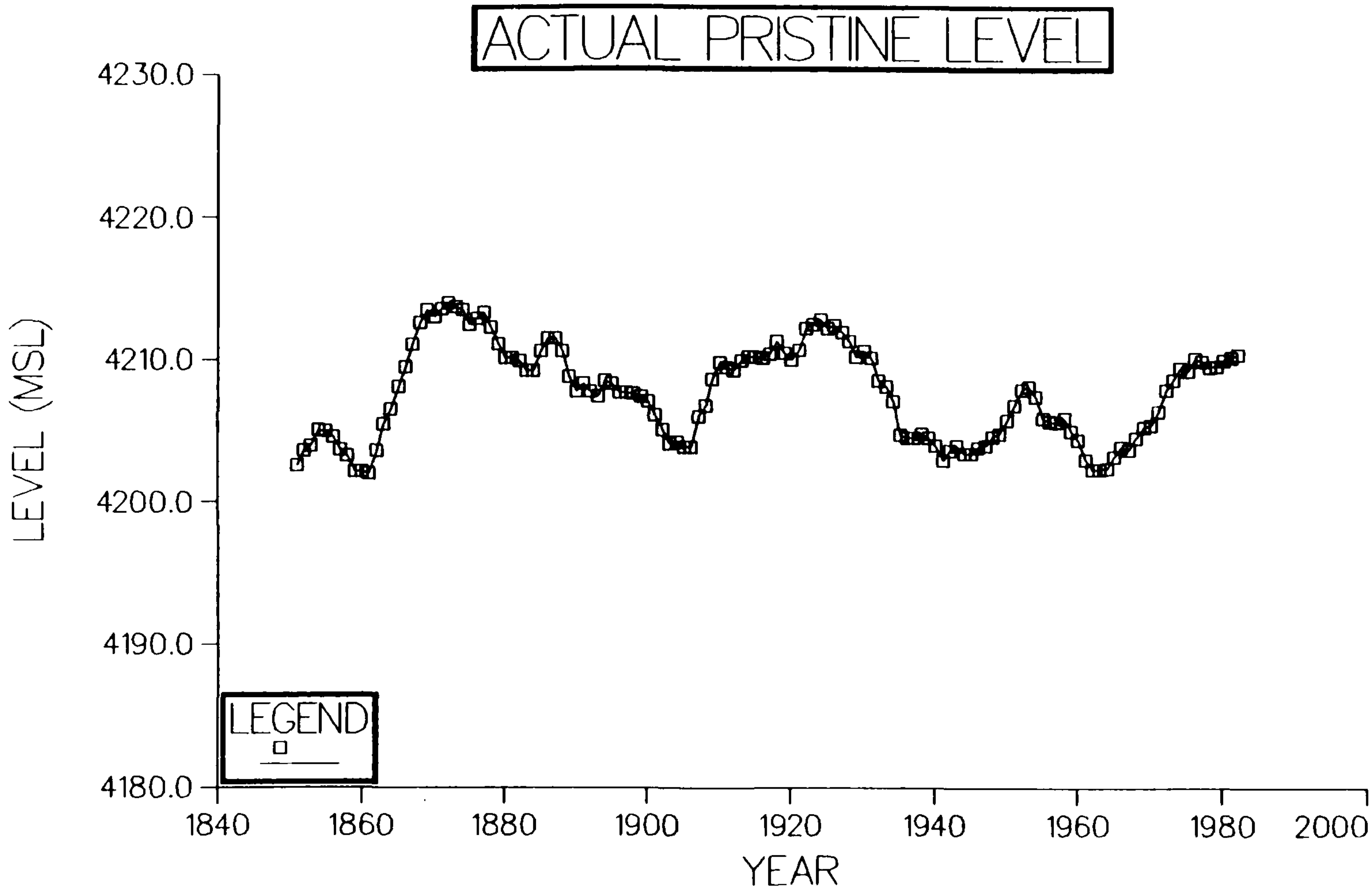


Figure 9. Actual pristine level.

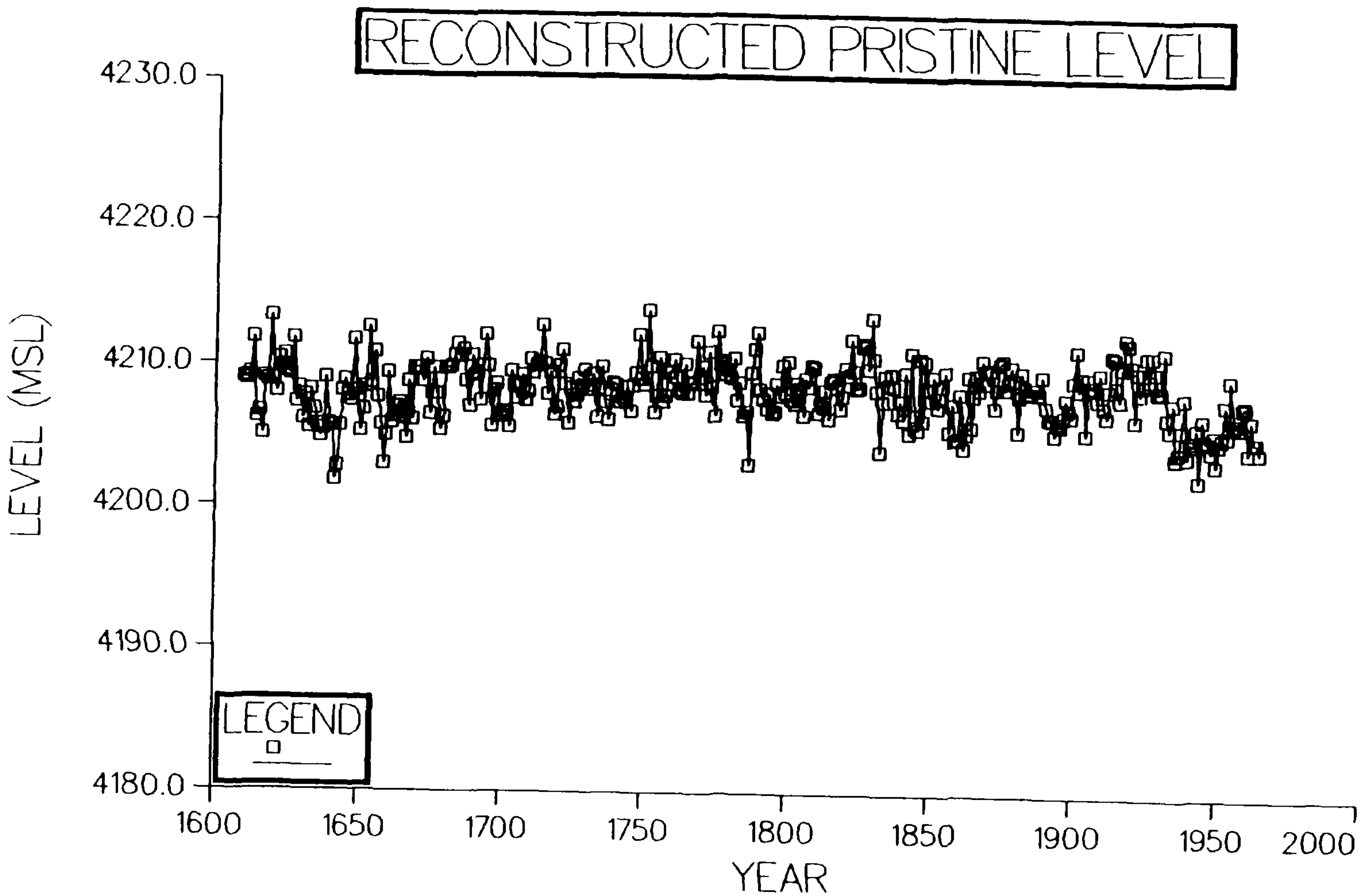


Figure 10. Reconstructed pristine level.

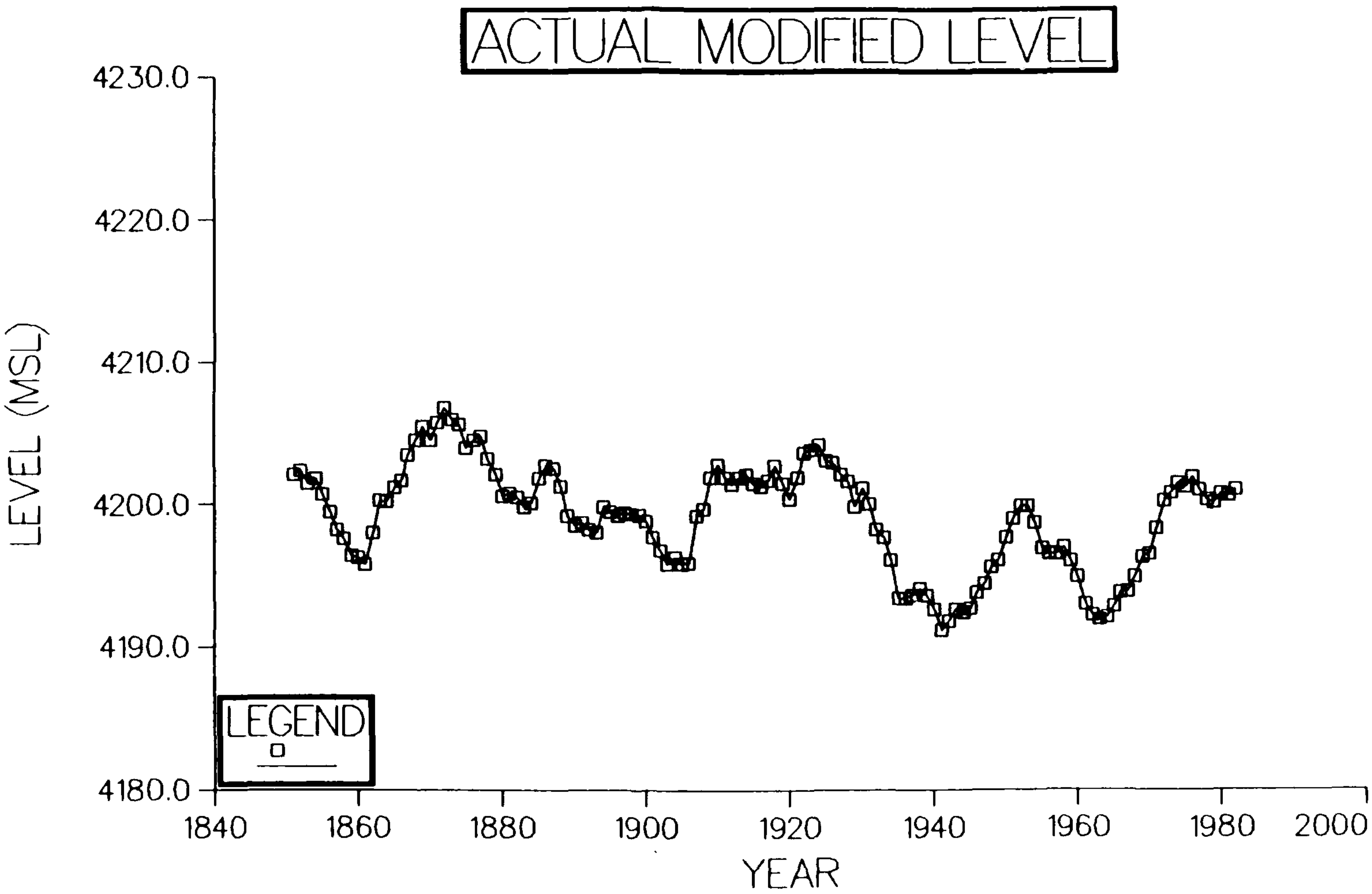


Figure 11. Actual modified level.

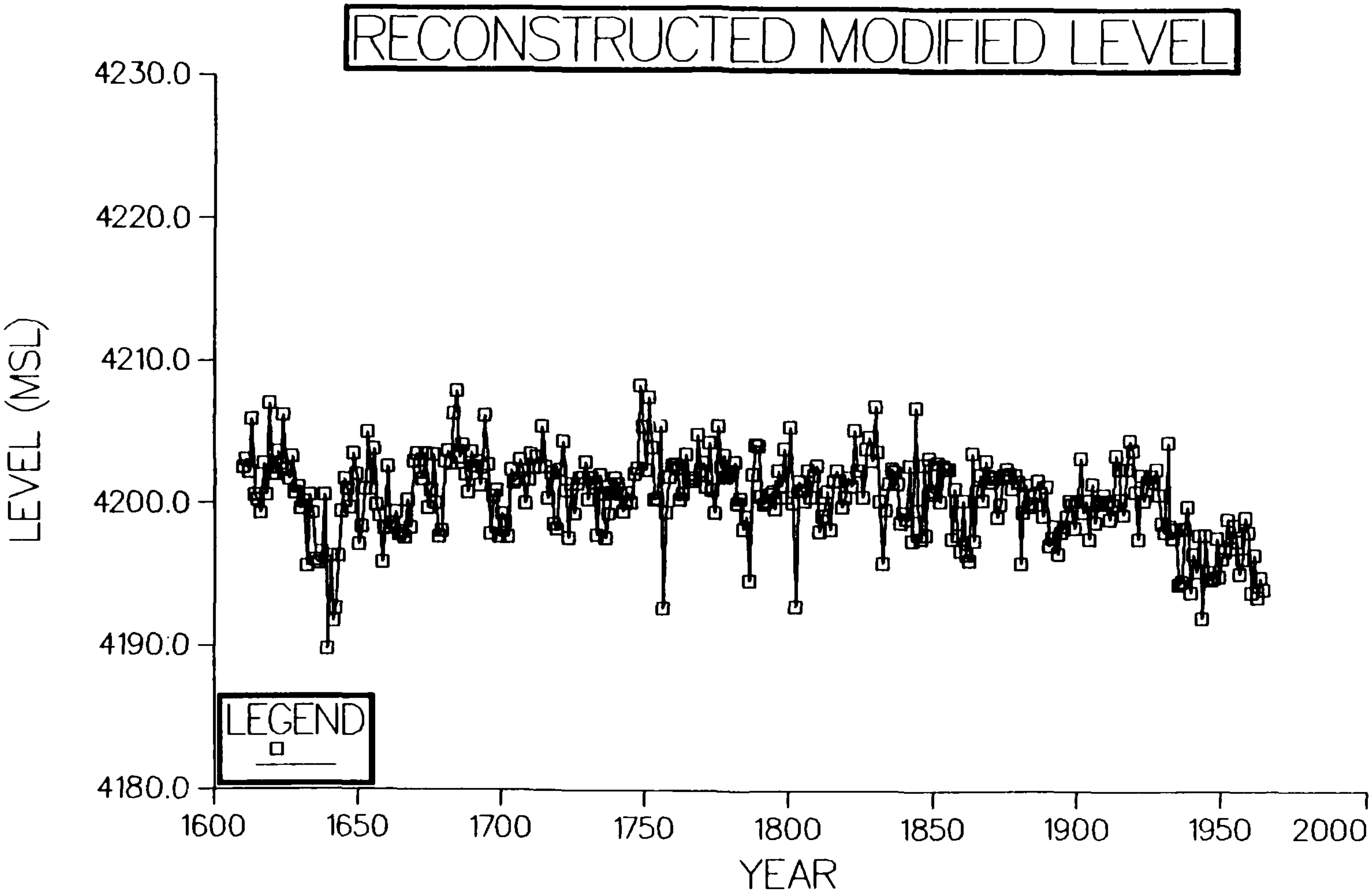


Figure 12. Reconstructed modified level.

conditions are more conservative than are actual pristine and modified data from 1851 to 1964. This leads to the conclusion that the lake was as high or higher than it is presently.

An unusual point of interest is, if the modified and pristine estimates are obtained merely by subtracting from or adding to the measured level of the lake, their R squared values should be about the same. But they are not. The modified level correlates relatively well to the tree rings. Its R squared value is comparable to that of the measured level R squared. But the value obtained from the pristine level is much poorer. This casts suspicion on the method for estimating the pristine level.

The reconstructed lake level from the second model and the reconstructed modified level correlate very well (R squared 81.4%). Not only are the general trends consistent, but the timing of the extremes are almost exact. The models are similar, but the model for the reconstructed pristine level shares more factors with the lake level model than does the modified model, but has an R squared value of only 55.3%. This is another indication that the pristine estimate of the Great Salt Lake is a poor one, and the methods used to derive it should be examined.

Finally, the tree ring sites were regressed on the surface area of the lake. Table 11 shows the resulting model, and Figures 13 through 16 show the reconstructed lake area through the years. Figure 17 shows the actual lake area. The regression model is identical to the second model used in reconstructing measured lake levels, and as such, Figure 13 is similar to Figure 4.

Table 11. Tree ring regression on lake area.

Tree Site	Coefficient
Intercept	1387322
BERRY	46177
CITY1	-575625
CITY2	812498
EMERY	-172087
HORSE	134828
PONY	-212386
DUCK	-91185
UINTAN	-100457
UPPER	202704
R Squared	49.5%

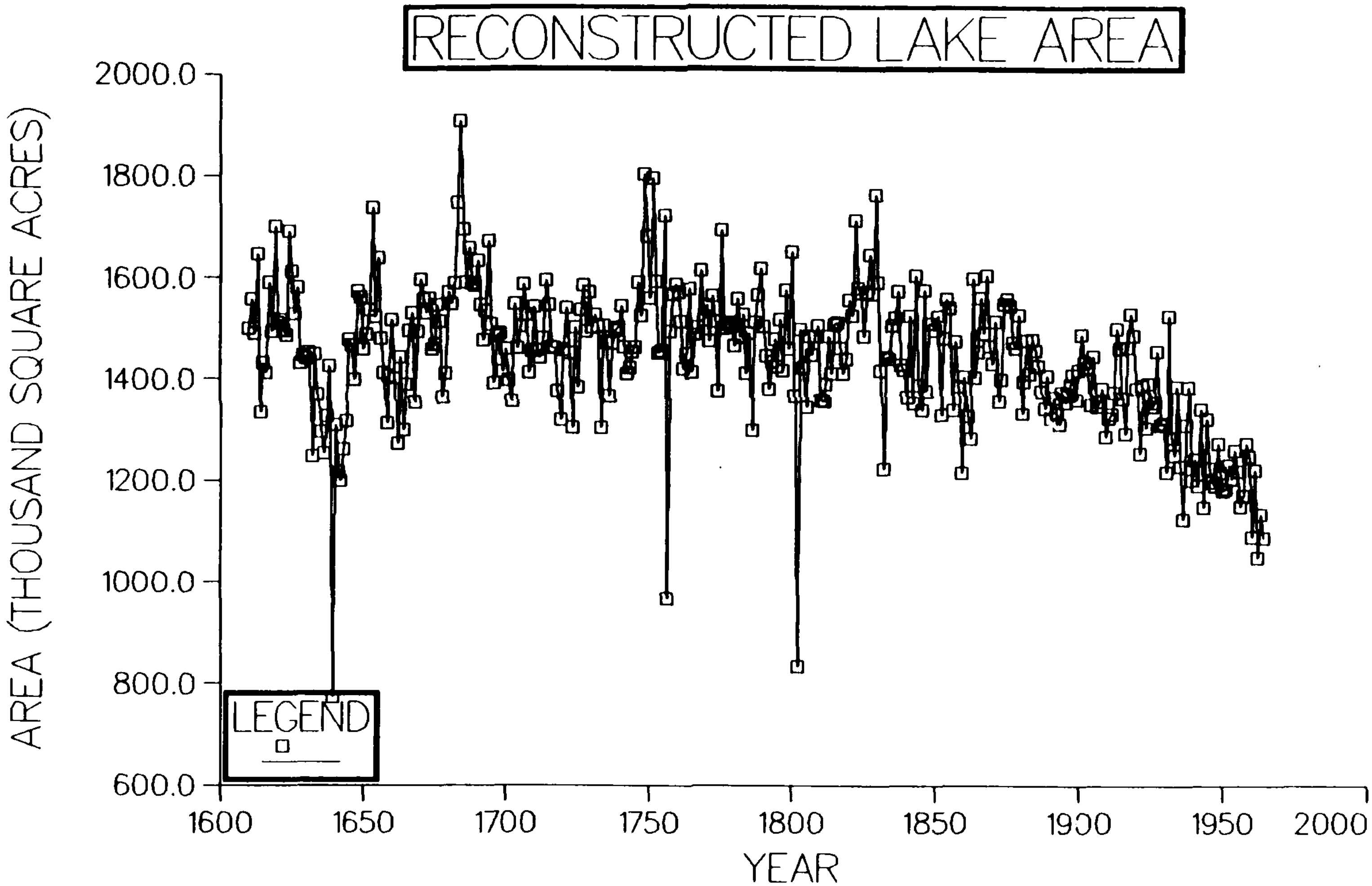


Figure 13. Reconstructed lake area (1610 - 1964).

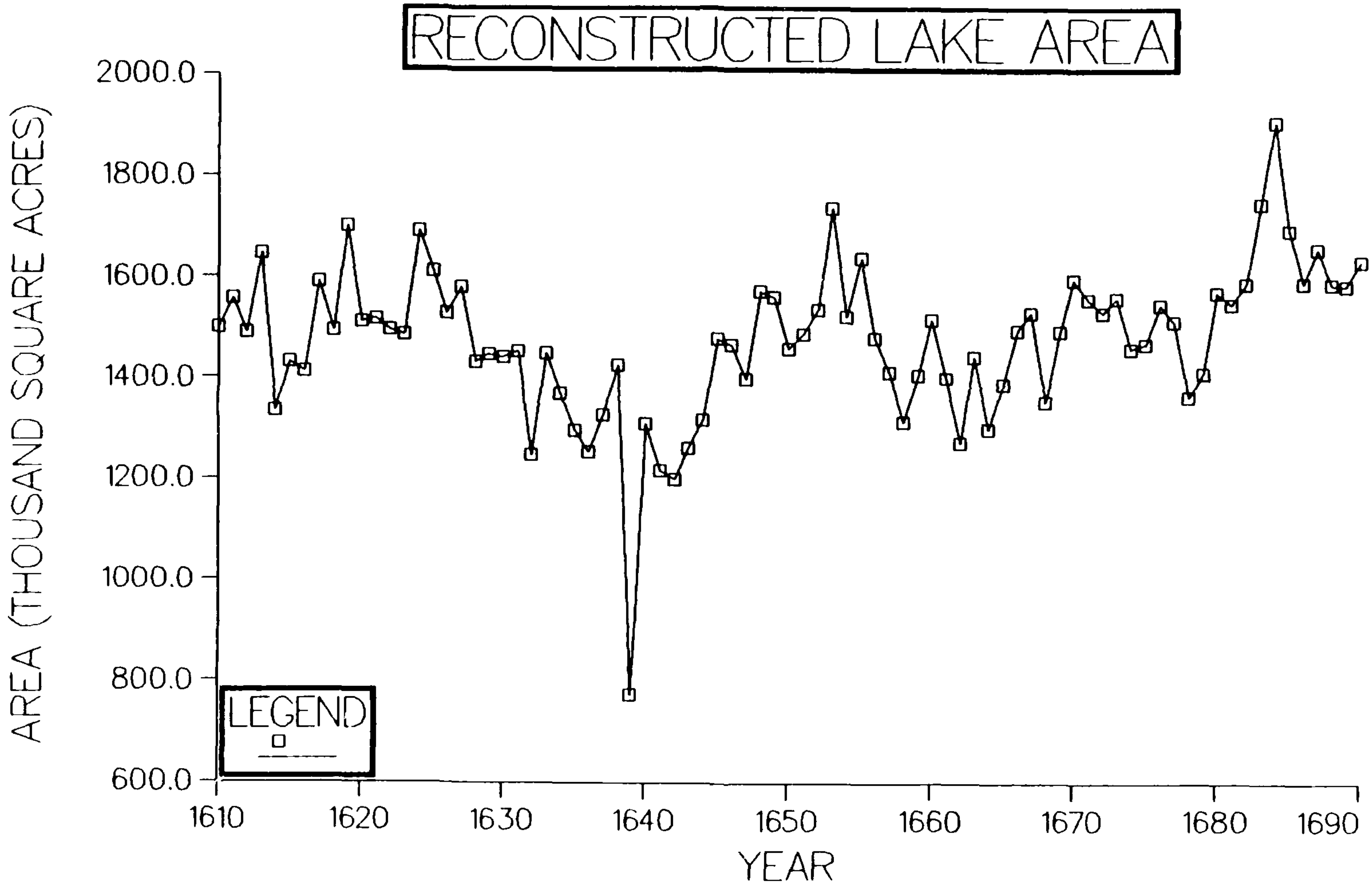


Figure 14. Reconstructed lake area (1610 - 1690).

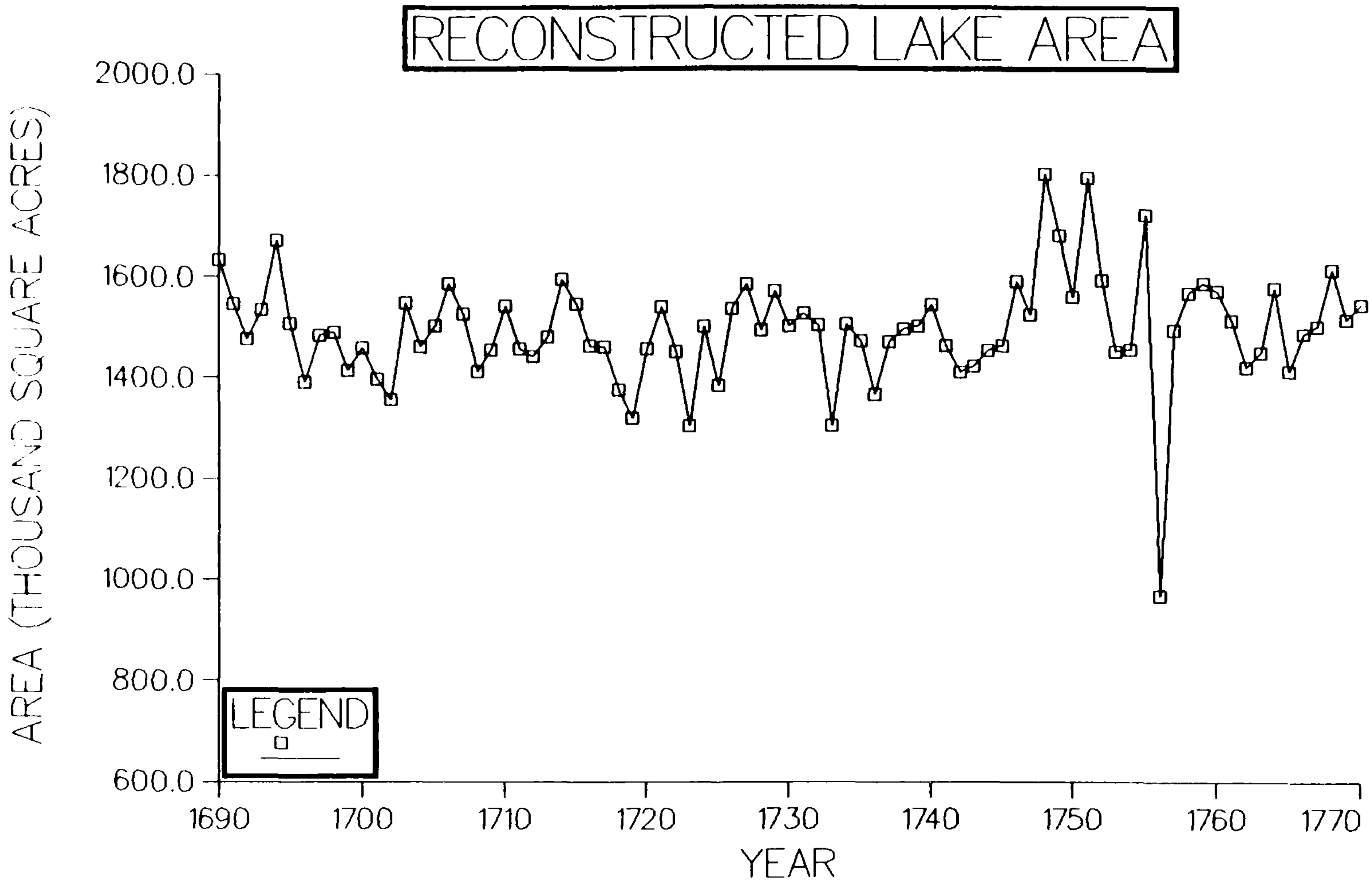


Figure 15. Reconstructed lake area (1690 - 1770).

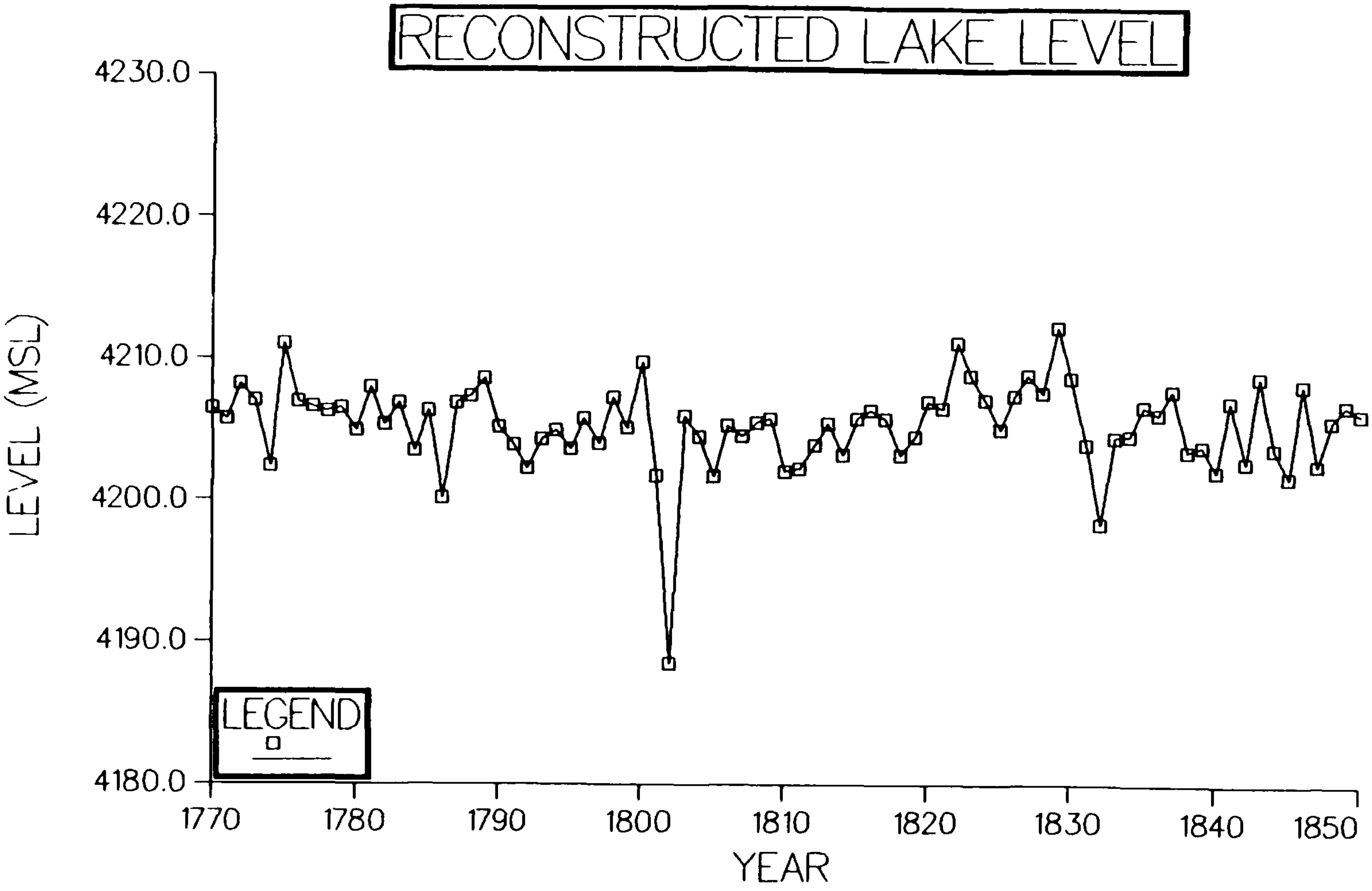


Figure 16. Reconstructed lake area (1770 - 1850).

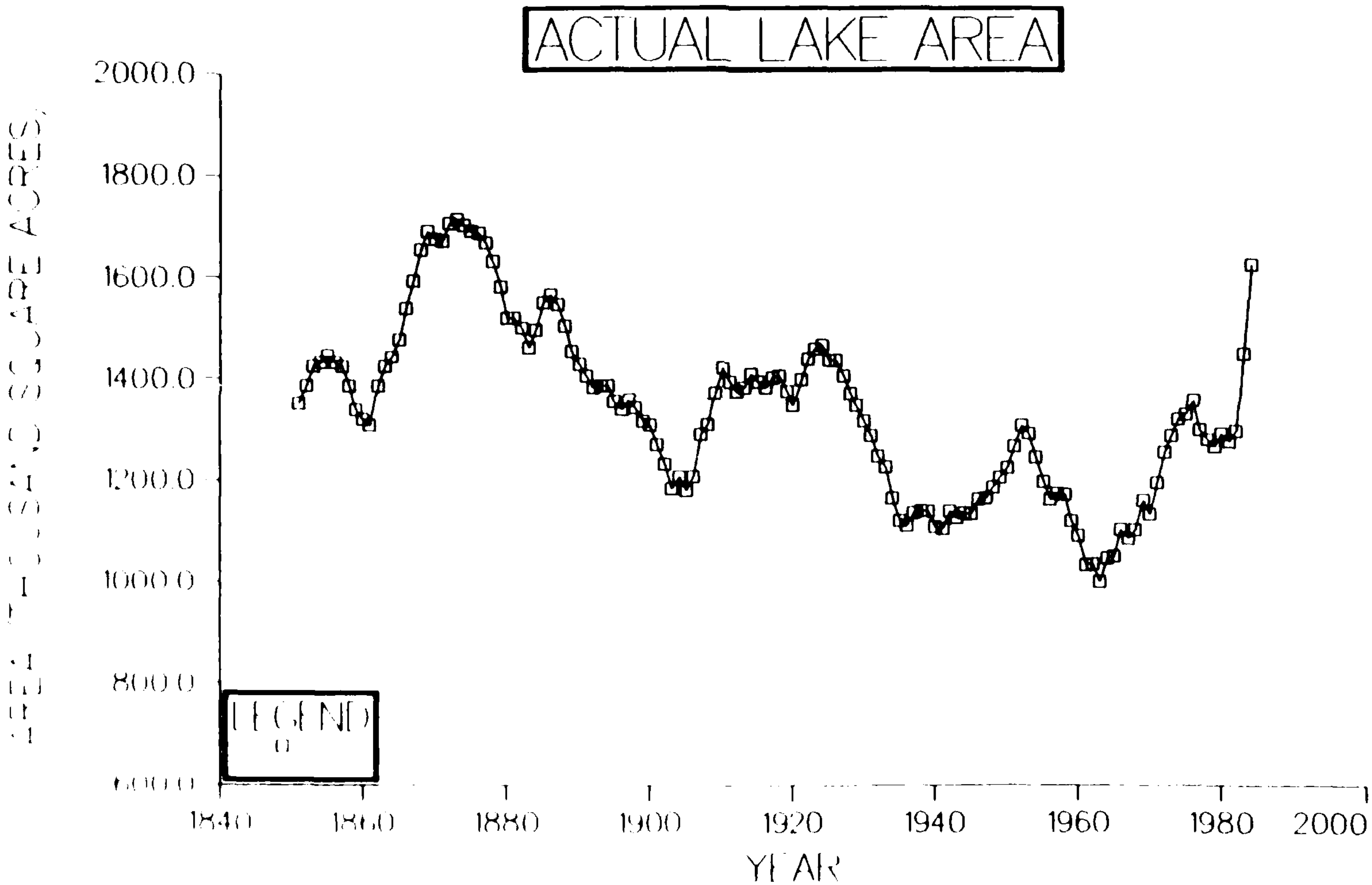


Figure 17. Actual lake area.

CONCLUSIONS AND RECOMMENDATIONS

The tree ring sites used in this study did not conform with previous findings showing good correlation of growth patterns when sites are separated by 100 miles or less. While some of the sites did share a high percentage of the common climatic signal when within this distance, others did not. The two sites furthest apart had a higher correlation than did sites less than five miles distant. The overall results were encouraging in showing the trees did not grow randomly, but did respond with similar growth patterns through the years. However, distance is not the only factor which should be considered. Other factors include such microsite conditions as soil type, pollution, and pest infestation. The most influential factor, though, is the effect of terrain in mountainous areas. Orographically induced cloud cover and precipitation, combined with differences in attitude with respect to solar radiation and storm tracks appear to be more important than spatial separation. Future researchers should use caution in generalizing growth patterns based solely on distance between sites, and should investigate other growing conditions.

Regression of precipitation data on tree ring indices would obviously be facilitated by setting up a network of automated collection sites closer to the tree sites and which better simulate the attitude of the tree sites to synoptic weather regimes. Barring the sudden windfall of research money necessary to accomplish this, it may be of benefit to put different terms in the regression equation. Winter

precipitation values had very little impact on tree growth, and could be replaced with winter temperature means, which may affect the health of the trees. In addition, a useable water term, obtained by combining precipitation and high temperature data, could be incorporated. More complex equations could also include differences in soil conditions and tree types.

Storm tracks are an obvious concern when trying to show precipitation regimes. Future studies in dendroclimatology should concentrate on relationships between synoptic weather patterns, in addition to precipitation values, and tree growth.

The reconstructed lake levels could be calculated more exactly with more tree ring site data. More sites could be sampled from the Bear River drainage basin, which should significantly improve the regression model. Bootstrap calculations could also be performed on the regression equation, perhaps allowing a better model to be calculated. More importantly, the limits on the regression coefficients, from their standard deviations, could be plugged into the equation, giving extreme maximum lake levels.

The initial question was, 'Is the current high lake level a freak occurance, or just the normal peak level in a cycle with a long period?' It may be stated with some confidence that the lake has been this high before, and possibly higher by as much as 5 feet or more. Recalling the four foot increase in lake level between 1982 and 1983 resulting in the flooding of 267 square miles, a rise to the conservative predicted maximum of 4217 feet MSL would cause serious problems to communities surrounding the lake. Should the lake approach 4226 feet MSL, the extreme predicted value, the results would be catastrophic.

The R squared values obtained in the regression of tree rings on lake levels are mediocre. Values of 80% would indicate this method is very good in reconstructing the lake, while values of 10% or so would show this method is poor, and could probably be abandoned. Luke warm results do not tell us which way to go. There are two important factors which limit the results of this study.

First, none of the tree ring indices used in this study are in the Great Salt Lake drainage basin. They were used as indicators of precipitation falling around the Salt Lake, and this limits the value of their data. Sampling of tree stands in the main drainage basin of the lake, primarily to the northeast, would go a long way in establishing the validity of this type of study.

The length of the data sets is the second limitation. While all the tree indices go back at least 270 years, they are not current. All sites were sampled before 1983, and most end in the mid to late 1970s, while one site which correlates significantly with the lake terminates in 1964. The most important flux of the lake in the last 50 years has occurred in the past 5 - 10 years, when the lake began to peak. This information is lost to the study, since, though we have lake measurements for this period, we do not have corresponding tree data. The tree sites should be resampled, and the most recent yearly data augmented to the existing tree site data.

In light of these limitations, the information and results of this study should be used prudently. This report should not be used alone to make decisions, but should be considered in conjunction with geologic, climatic and economic information so as to best use and manage the waters of the Great Salt Lake.

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